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ADVANCED SHIP SYSTEM CONCEPTS FOR HYDROGRAPHIC SURVEYING

DW Murphy
WS Morinaga

September 1980

Prepared for
Defense Mapping Agency

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Commander

HL BLOOD
Technical Director

ADMINISTRATIVE INFORMATION

The Defense Mapping Agency (DMA) has the mission of producing adequate nautical charts for all U.S. shipping in foreign and international waters. With the current assets, this task will require at least two hundred years to complete for accessible waters. Defense Mapping Agency funded the Naval Ocean Systems Center (NOSC) to investigate new ship systems concepts for improving the capability. The work was performed on Task DMA PE 63701B/3201/270, Data Collection.

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Under authority of
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An investigation is reported of advanced ship systems concepts for conducting the hydrographic survey mission of the Defense Mapping Agency. Advanced concepts for improving the survey rate and reducing the operating costs are discussed.

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OBJECTIVE

This study was conducted to investigate advanced ship systems concepts for conducting the Hydrographic Survey Mission of the Defense Mapping Agency. The objective was to look at advanced concepts for improving the survey rate and reducing the operating costs.

RESULTS

The concepts considered in this study were limited to those based on new designs and did not address existing fleet assets. These concepts included various size Small Waterplane Area Twin Hull (SWATH) support ships, new small hydrographic survey launches (HSL's) for very shallow water surveying, large 50-foot manned HSL's for extended open ocean surveying, and remotely piloted, unmanned, surface craft and submersibles.

Results of the study indicate that the present capability is limited by a shortage of assets, old equipment and a high personnel turnover rate. Concepts recommended for improving the capability are:

a. Utilize the SWATH hull design in any new mother ship design.

b. A small, low cost, manned HSL is required for near shore shallow water surveying. This should utilize automated data recording and navigation as much as possible to reduce manning requirements.

c. Both the 50-foot manned HSL and the remote controlled unmanned semisubmersible look attractive for extended moderate to deep water surveying in parallel with the mother ship. The manned HSL offers proven technology with limited endurance due to sea state and operator fatigue and suffers from its large size. The remote controlled semisubmersible can operate in higher sea states, and does not have a crew on board. It does require a significant development investment.

RECOMMENDATIONS

It is recommended that additional work be done to identify the specific future survey mission requirements in terms of deep water and very shallow water surveying and the resources available to develop and operate a given system. The size of the mother ship is driven by the HSL or auxiliary survey craft complement it must support. The auxiliary craft types and mix are driven by the water depth to some extent and the level of technology which can be developed and supported both in terms of dollar cost and staffing.

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INTRODUCTION

BACKGROUND

The Naval Ocean Systems Center (NOSC) was tasked by the Defense Mapping Agency (DMA) to investigate the applicability of advanced ship system concepts to hydrographic surveying.

The DMA is required by law to provide adequate nautical charts for all U.S. shipping in foreign and international waters. The fundamental mission areas (6-300 fathoms) backlog totals approximately 1.8×10^6 square miles. Assets presently available to DMA for conducting this task are two dedicated hydrographic survey ships, the CHAUVENET and HARKNESS, plus some small contract vessels. With the present assets, it is estimated that it will take well over 200 years to complete only the basic areas backlog.

STUDY OBJECTIVE

The objective of this study was to investigate the application of advanced ship systems to the hydrographic survey mission and recommend the more promising concepts for upgrading the survey capabilities.

APPROACH

The study was performed by the following approach:

(1) Pertinent background information was gathered on the present survey methods, limitations, problems and desired improvements. This was done by interviewing DMA and Naval Oceanographic Office (NAVOCEANO) personnel and observing an actual survey operation.

(2) A simplified model of a survey operation was developed and used to analyze the effect on survey rate (survey miles/day) by changing survey parameters.

(3) Various advanced concepts were brainstormed and analyzed for possible applications as survey platforms.

(4) The more promising concepts were selected and recommended for further investigation.

CURRENT SURVEY SYSTEM

SYSTEM DESCRIPTION

The U.S. Naval Oceanographic Office performs the hydrographic surveys for DMA. Prior to FY79, two ships, the USNS CHAUVENET and the USNS HARKNESS, were available to DMA for surveying. In FY78, use of the HARKNESS was lost. The majority of the survey operations are now performed by the one dedicated ship. Some surveys are performed with smaller ships or boats that are leased or rented. HARKNESS is reportedly scheduled for reactivation in FY 1981.

The CHAUVENET (figure 1) was launched in 1968. It has a displacement of 4200 tons, and is 393 feet long with a beam of 54 feet and a draft of 16 feet. The ship is diesel powered and has a single shaft capable of 3600 HP. The complement capability of this ship is 13 officers, 150 enlisted men and technical personnel, and 8 scientists. These numbers vary with the type of operation. The maximum speed of the CHAUVENET is 12 knots and its normal survey speed is 10 knots. This ship normally operates on a 28-day cycle: 23 days of survey and 5 days in port for repairs and supplies.

The CHAUVENET was designed to perform hydrographic and oceanographic surveys. It carries four hydrographic survey launches (HSL), as shown in figure 2, and has a helicopter hangar and platform to support helicopter operations. The ship is operated by the Military Sealift Command (MSC). The cost for the CHAUVENET was $6,261,000 for FY79. Besides operating the ship, some of the crew directly supports the survey operations. A Navy detachment on the ship, Oceanographic Unit 4, has several functions, including operation coordination, navigation aids, helicopter support, HSL operation and equipment maintenance. The NAVAIDS personnel establish and maintain the navigation sites. Normally, two to three sites are simultaneously operational. The Navy personnel maintain the HSL's and also perform the HSL surveys. The HSL crew numbers about seven men per boat. Navy electronic technicians operate and maintain the electronic equipment that is used for the surveys. A Navy helicopter detachment is onboard to conduct operations in support of the navigation shore stations. This detachment consists of the pilots and maintenance crew and numbers about 18 people.

The third contingent onboard the CHAUVENET is the NAVOCEANO group, consisting mainly of civilian hydrographers and technicians. They produce the survey plans, and check and process the collected hydrographic data. NAVOCEANO electronic technicians support the Navy technicians. The normal NAVOCEANO contingent numbers approximately eight.

The primary navigation system used for surveys is the ARGO DM-54, manufactured by Cubic Western Data. ARGO replaces Raydist, a similar but shorter range system. ARGO is a radiolocation, phase-comparison system that operates in the frequency band of 1600 to 2000 kHz. It operates with two to four fixed stations (shore stations) and up to eight mobile stations (ship and HSL's). The maximum range is 400 nm during the day and 300 nm during the night. System accuracy is 0.05 lanes, or about five metres.

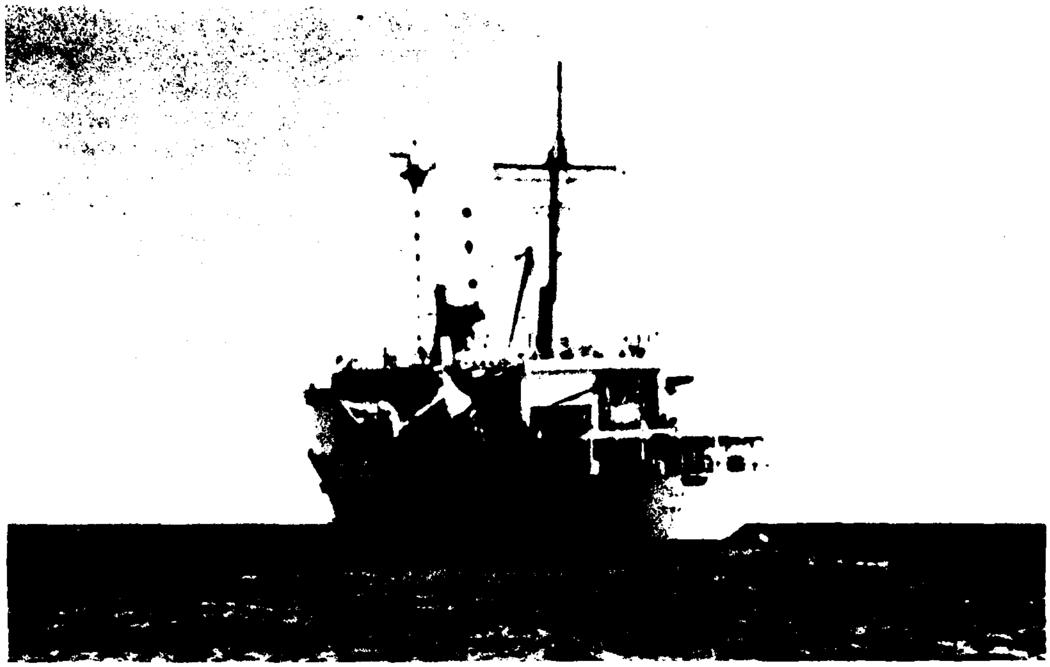

Figure 1. USNS CHAUVENET.

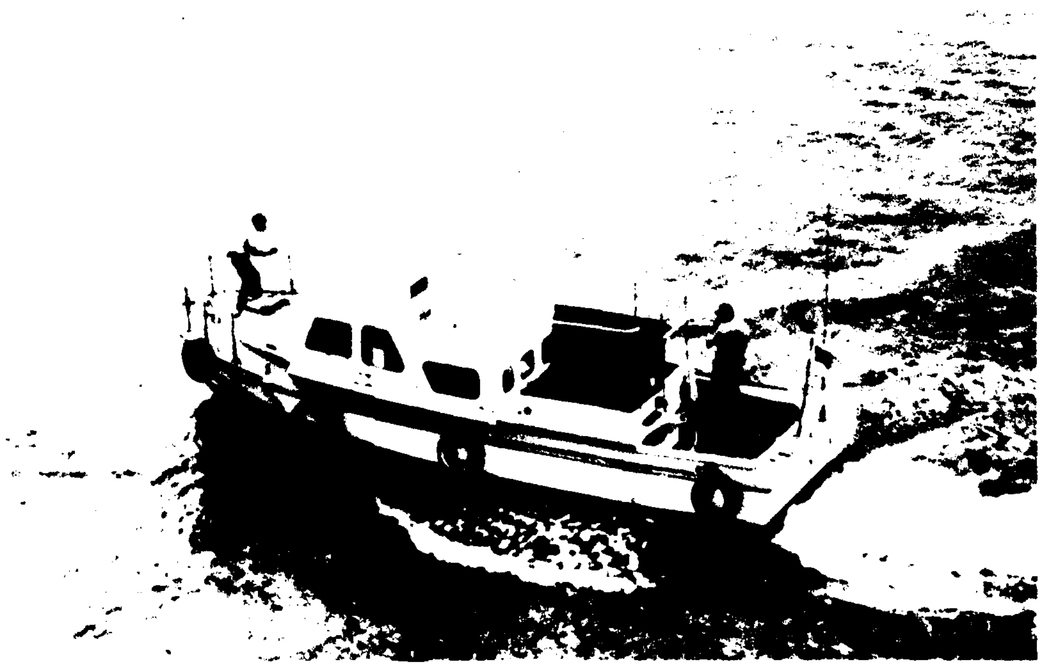

Figure 2. Hydrographic survey launch (HSL).

Motorola's Miniranger III system is also used for short ranges. This is a radar pulse ranging system and is limited to line of sight, or about seven to ten miles.

Shore-based navigation stations are required at each survey area for the navigation references. Each station is manned by five to six Navy personnel. The sites are supported logistically from the ship. Resupply is usually performed by helicopter. Since the sites can be in remote and/or rugged areas, some of the navigation stations may take several days to establish. The area around the antenna must be cleared and there must also be a clear area for the helicopter to land or hover. A Geoceiver is normally used to obtain a geographical fix for the site. Approximately 40 good satellite passes are required to obtain an accurate position fix. If a known geographical benchmark is nearby, the site's coordinates can be obtained using geodetic survey techniques.

The major problems with the navigation system are the large amounts of time and resources required to establish and maintain the shore stations. After the navigation station is established, the ship must periodically return to within helicopter range to resupply fuel, food and water. In addition to the physical problems of establishing the navigation stations, there are political problems. Local cooperation and approval are required prior to setting up the sites, and frequency approval is also needed for the navigation radio frequencies. This requires liaison with the local government and communities.

The navigation equipment also has operational shortcomings. ARGO is susceptible to weather interference, and to ground interference around the antennas. These interferences can produce calibration errors. Errors can also be produced when the ship or HSL makes an abrupt change in course. The ARGO system is limited to a maximum range of 400 miles, requiring new navigation shore stations to be established as often as the survey area moves out of the station's range. This system also requires a dedicated operator to count and annotate the lane number on the strip chart as a backup in case there is a temporary loss of the radio signals. The ARGO DM-54 system has a 15-knot speed limit in the range-range mode.

The HSL's navigation equipment is calibrated each time they are launched and recovered. Calibration takes 10 to 30 minutes per HSL, reducing the available survey time.

The Miniranger range limitation of seven to ten miles severely restricts the use of the system and requires more frequent establishment of shore stations than for the ARGO system.

In addition to the navigation equipment, the ship's survey system consists of fathometers, computers and plotters. The ship has a narrow beam fathometer and a wide beam fathometer. The narrow beam fathometer is the Harris 853D Echo Sounder, manufactured by General Instruments Corp. The depth range is 24 to 6,000 fathoms (44 to 11,000 m). It has a beam width of 2-2/3 degrees. It operates at 12.15 kHz and a 4 kW power. It is mounted on a gyro-stabilized platform. The wide beam fathometer is the Alpine 495B. It has a range of 2,000 fathoms (3,600 m) and a beam width of 45 degrees. It operates at 12 kHz and at 2 kW power.

Two Digital Equipment Corporation PDP-9 minicomputers support the operation. One computer is used to plot the ship's track in real time, while the other normally processes survey data. Programs are loaded by paper tape or magnetic tape. Navigation data normally are interfaced directly to the computer. Teletypewriters are also used as input/output devices for entering data or commands.

Two CalComp plotters are interfaced to the computers. The plotters are used to plot the ship's track and to produce the track sheets for the survey areas.

A Wang 2200S computer is used to digitize and record the fathometer strip chart traces. A magnetic digitizing table is connected to the Wang computer and the digitized data are stored on cassette tapes.

The main problems with the survey equipment are reliability and maintenance. Much of the equipment is old or obsolete. The PDP-9 computers are no longer manufactured. Repairs are made by cannibalizing parts from other PDP-9's. The Alpine fathometer is no longer being manufactured.

The CHAUVENET has a helicopter pad and hangar to support one Bell UH-2 helicopter. The helicopter's main function is to support the shore stations. It flies at a speed of 100 knots, has a range of 250 nautical miles and a flight time of 2.5 hours. The normal flight crew consists of two pilots and two crewmen.

Four hydrographic survey launches are carried aboard the CHAUVENET. The HSL is a 36-foot long, 11-foot beam fiberglass boat. It is diesel powered and has a maximum speed of ten knots. Uniflight Boat Company manufactured the HSL's at a cost of $133,750. The HSL's are equipped with the ARGO DM-54 navigation equipment and a Raytheon DSF-600 digital fathometer. The fathometer operates at 40 kHz and 200 kHz, and has a range of 600 metres. The crew normally numbers about seven: boat officer, coxswain, plotter, navigation reader, fathometer reader, engineer and a reserve.

The main limitations of the HSL are its endurance and sea state capability. It must be recovered at the end of the day, or sooner if the weather deteriorates. The HSL's endurance limits their survey time and restricts the movement of the mother ship.

Another drawback is that the HSL survey operations require a large crew. Bathymetric data are hand recorded and the navigation track is hand plotted. Manual data logging introduces additional chance of error and there is no real time check on the validity of the data. A day's track may be found invalid when the data are checked at the end of the day on the ship. There is also a delay in correcting the HSL course because of the delay in manually plotting the location of the HSL. When using the ARGO navigation system, the HSL track normally follows a constant navigation lane, which is a curved line. This is difficult for the coxswain.

HSL operation is limited to sea state three. Construction is of light fiberglass and has proven to be easily damaged.

Like the ship, the HSL has equipment maintenance and operational problems. These problems are primarily related to the lack of experienced crews for operating and maintaining the equipment. The lack of experience results from short duty tours with the survey ship and limited (by available time) training. By the time the technician becomes fully knowledgeable on the equipment, he is near the end of his tour of duty.

TYPICAL HYDROGRAPHIC SURVEY SCENARIO

When surveying a new area, the first operation is to select the location of the shore navigation stations and to obtain approval for using these sites. Some of these sites require considerable preparation prior to installing the antenna and landing the helicopter. Using satellite receivers or geodetic surveying techniques and benchmarks, an accurate position fix of the site is obtained. After the navigation stations are established and operational, the navigation equipment onboard the ship is calibrated to the shore stations.

As the navigation system is being made operational, the NAVOCEANO personnel produce track sheets of the survey area for directing the ship and the HSL's during the survey and plotting of survey data. For a typical operation requiring the use of HSL's, the mother ship launches the HSL's at the beginning of the day, about 0800. The HSL's are launched near the vicinity of their survey area and their navigation equipment is calibrated by having the HSL individually follow directly behind the ship and check lane readings with the ship's readings. Calibration takes 10 to 30 minutes per HSL.

After the navigation equipment is calibrated, the HSL fathometer's calibration is checked by lowering a steel beam below the boat. The HSL then transits to its assigned area to conduct the survey. If it is a new area, the HSL normally plots crosscheck lines before running its survey lines. Crosscheck lines are sounding lines that are used to verify and evaluate the accuracy and reliability of the surveyed depths and positions (figure 3). The crosscheck lines are perpendicular to the survey lines and 10 times the lane width of the survey lines. The lane widths between survey lines and between crosscheck lines depend on the required scale of the survey area.

The HSL follows the predetermined tracks on the boat sheets. The navigation reader feeds the navigation data to the plotter, who manually plots the HSL's track on the sheet. The plotter then directs the coxswain to steer on a course that will follow the predetermined tracks. During the survey, time is periodically annotated on the fathometer chart and on the ARGO lane counter strip chart. Also, navigation data and fathometer readings are recorded in the logbook.

If the ARGO DM-54 system is used, the survey lines are normally curved to follow the navigation lanes; i.e., the track follows a constant navigation lane. When the Miniranger navigation system is used, the track lines are straight.

While the HSL's are conducting their survey, the ship transits to its survey area, which is usually in deeper water. The ship also runs crosscheck lines. Navigation data and fathometer readings are fed directly into the computer. The ship's track is normally plotted in real time by the PDP-9, using the CalComp plotter. A technician constantly monitors the

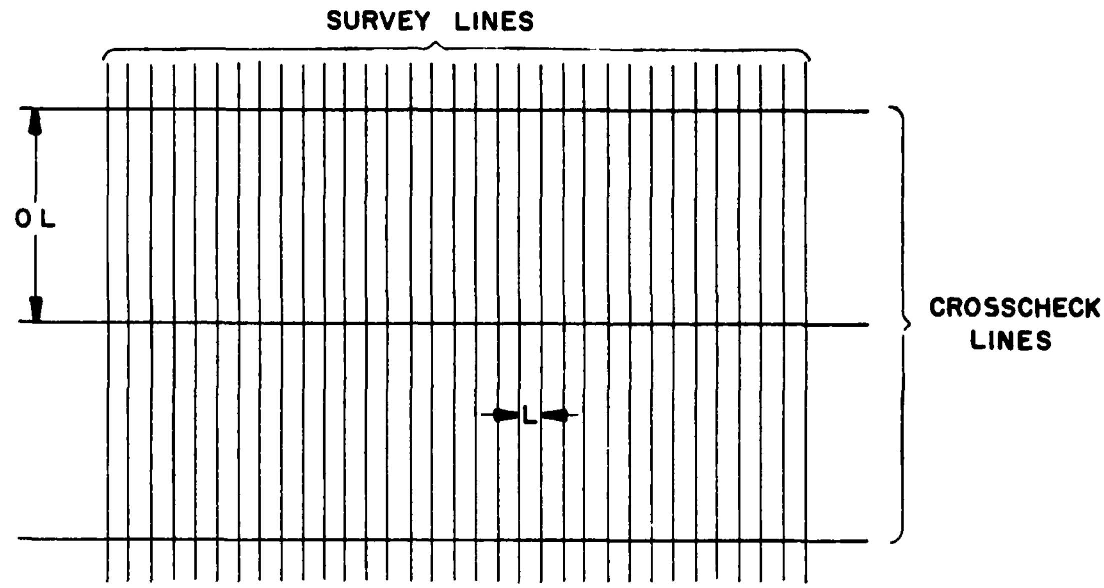

Figure 3. Crosscheck lines and survey lines.

ship's track on the plotter in the survey control room. As the ship deviates from the prescribed track, the bridge is directed by intercom to a course bringing the ship back on track. The tracks of the ship are straight lines. During survey operations, the ship remains within four hours transit time of the HSL's. At the end of the day, the ship transits back to the HSL's and at about 1600 begins to recover them.

Prior to recovery, each HSL's navigation equipment is again checked. After the HSL's are recovered, the ship continues its own survey throughout the night, while that day's HSL data are checked and processed. In the morning, the ship transits to the shallow survey area to again launch the HSL's for another day of survey.

In addition to supporting the HSL's, the ship periodically transits to the vicinity of the shore stations to resupply the sites by helicopter. It also transits within the helicopter range of a nearby town where mail can be delivered and received.

From the data of the Panama operations (appendix A), the average survey rates were 190 miles per day for the ship and 154 miles per day for the HSL. Appendix A also describes some typical operational problems.

SUMMARY OF PROBLEMS

The primary factor limiting DMA's present survey capability is that there are only two dedicated ships. These ships are slow, require a large crew and are very expensive to operate.

Factors limiting the ship's survey efficiency are navigation system establishment and maintenance and equipment reliability. The present navigation system requires that considerable manpower, time and effort be invested to establish and maintain the shore stations. The system is range limited, and susceptible to weather interference and errors caused by abrupt changes in the ship's course. The ship's survey time is reduced by the amount of time the ship has to suspend survey operations in order to support the HSL's and shore stations.

Some of the equipment is old or obsolete. The DEC's PDP-9 computers are obsolete: their reliability is a problem. Repairs are made by cannibalizing other in-house PDP-9 computers. The Alpine fathometer is no longer manufactured.

Lack of personnel training has reduced the survey efficiency by requiring resurvey of areas with erroneous data, halting a survey because of inoperative equipment and slowing operations due to personnel lack of familiarity with the equipment. The training problem is created by very limited training time and the short duty tours of the personnel aboard the survey ship.

One of the main limitations of the present HSL's is that they cannot operate overnight, requiring recovery at the end of each day's operation. This reduces the available survey time of the mother ship since it must remain close to the HSL's and must spend time to launch, calibrate and recover them. HSL operations are limited to conditions of sea state three or less and survey at only eight knots. The small size of the HSL requires this support but also allows the boats to operate in confined shallow areas, which is to their advantage.

Data recording and plotting are performed manually, requiring a large crew. Since there is no real time plot of the track, data cannot be checked in real time. Errors in data are not discovered until they are processed after the completion of the day's survey. Errors can invalidate a whole day's work. The HSL itself has proved to be fragile.

CONCEPTS

CONCEPT GENERATION

The objective of this study is to look at new surface ship system concepts for improving the hydrographic survey area rate and operational efficiency. Efficiency includes streamlining the operation to require less labor and to reduce the system size and costs. DMA is supporting the development of advanced sensor systems which, if successful, will greatly increase the efficiency of performing shallow water charting or, if not utilized in a quantitative sense, will at least allow *a priori* knowledge of shallow areas, allowing more efficient division of effort between the large craft and HSL type craft. The improved sensor systems include:

(1) Utilization of data from satellite borne multispectral scanners such as those used on Land Sat.

(2) Airborne Scanning Laser - This sytem can be deployed in a helicopter or fixed wing plane and is under development by Naval Ocean R&D Activity (NORDA).

(3) Multispectral Scanning System - This system would be deployed on fixed wing aircraft. It is being developed by the Naval Coastal Systems Center.

(4) Photogrammetry.

All of these systems are limited to shallow waters and are affected by water clarity, weather and time of day. If utilized, they should significantly reduce the requirement for the use of HSL's for large area shallow water surveying, thus increasing the overall efficiency. They will not replace the requirement for HSL surveying, but will allow these operations to be reduced and to be focused on areas seaward. Thus, while the requirement will be reduced, small boat surveying will still be very much required and the capability for supporting them must be included in any new surface craft.

Based on discussion in the previous section, requirements for any new system should be directed at reducing ship size, reducing crew size, increasing operational efficiency, automating as many operations as possible and increasing the percentage of survey time to the total operation time. These can be accomplished by:

(1) Reducing ship's non-survey time

- HSL support
- Navigation station support
- Down time due to sea state
- Increase transit speed

(2) Increasing survey rate

(3) Higher speed

(4) More survey vehicles per ship

(5) Improving system reliability

(6) Improving the data handling function

(7) Automating functions.

At the outset of the study many concepts were brainstormed for providing an improved capability. Most of the concepts consisted of a large, long-range mother ship which would serve as a base of operation in remote areas and smaller auxiliary craft supported from the mother ship which would provide the required shallow water survey capability and an overall increased survey rate through parallel operation. The more practical of these concepts are summarized in table 1, Mother Ship Concepts, and table 2, Auxiliary Concepts.

Table 1. Mother ship concept summary.

CONCEPT	ADVANTAGES	DISADVANTAGES	COMMENTS
Existing Survey Ships	1. Exists. 2. Known capabilities.	1. Serious limitations in auxiliary craft launch and retrieval due to ship motion. 2. Very large crew. 3. Slow speed. 4. Old equipment/could update.	The capability exists but has demonstrated its limitations. In the future, where fuel economy requirements and manpower restrictions will be imposed, constructing additional ships of this design does not appear to be justified.
New Smaller Monohull	1. Lower procurement cost than building more CHAUVENET class ships. 2. Smaller crew than above. 3. Could be automated and fitted with more efficient systems.	1. Handling of auxiliary craft even more sea state limited than above. 2. Limited deck space for helo ops and HSL storage.	Could provide some savings in operating costs due to smaller crew and better fuel economy but at the price of an even more limited operational capability.
Use Existing Navy Assets Such as LSD's	1. Exists. 2. LSD has large well and could support several large (50-foot) HSL's capable of extended survey.	1. Very limited launch and retrieval capability in medium seas. 2. Danger to HSL and crew due to wave surge in well. 3. Very large crew required.	The use of an LSD with larger, longer endurance HSL's appears attractive on the surface but the LSD poses serious limitations in the safe launch and retrieval of the still small HSL's in heavy seas and appears very inefficient in terms of crew size and operating costs.
SWATH	1. Provides very good sea keeping for crew comfort and HSL support with small size. 2. Reduced manning requirements. 3. Reduced fuel requirement. 4. Helo support from small ship.	1. New design - not presently in Navy use. 2. Reduced total payload fraction from monohull.	Could satisfy the survey mission requirements while providing smaller size, improved sea keeping and more efficient operation. The reduced payload fraction does not appear to affect the survey mission.
Hydrofoil	1. High transit and survey speeds (up to 50 knots). 2. Good stability while underway.	1. Reduced seakeeping at low speed (same as a monohull). 2. Very costly technology. 3. Limited payload and deck area. 4. Limited range.	The hydrofoil is currently being used for high speed patrol craft and passenger ferries. Its range is limited and it must be underway to enjoy low response to the sea which limits its ability as a helo or HSL support craft.
Surface Effect Ship	1. High transit and survey speeds.	1. Costly, high performance, advanced technology subsystems. 2. Response to sea when at zero or reduced speed.	The SES will provide a high-speed platform, but at the cost of very high performance equipment, and its attendant high production cost and upkeep cost.

Table 2. Auxiliary craft concept summary.

CONCEPT	ADVANTAGES	DISADVANTAGES	COMMENTS
Present 36-foot Navy HSL	1. Design exists. 2. Known capability. 3. Provides operator on site for control in very shallow water.	1. Has proven fragile. 2. Limited to daylight operations; must be recovered daily.	Efficiency could be improved by automating the data taking functions to reduce crew requirement.
28-foot Aluminum HSL	1. Used by NOAA in their near shore hydrographic survey missions. 2. Proven rugged. 3. Reduced storage volume.	1. Slightly lessened sea state capability over 36-foot HSL. 2. Less crew space. 3. Limited to daylight operations; must be recovered daily.	A good design if a daylight-only small boat capability is desired. Demonstrated capability.
50-foot Monohull HSL	1. Better habitability for crew. 2. Capable of 24-hour operation in moderate seas. 3. Not required to be recovered daily by mother ship.	1. High initial cost. 2. Higher value would limit shallow water operations to known safe areas. 3. Small HSL would still be required for very near shore operations.	The larger HSL offers a significant potential increase in operating efficiency by allowing around-the-clock operation in moderate seas and the ability to remain out overnight in shelter even in heavy seas. Due to the high value of the large HSL, small HSL's will likely still be required for surveying very shallow areas.
50-foot SWATH HSL	1. Good seakeeping characteristics. 2. Same advantages as 50-foot HSL.	1. Deep draft. 2. Probably more costly than equivalent length monohull. 3. Near minimum reasonable length for SWATH design. 4. Large plan area (large area required for transport aboard the mother ship).	Not advisable for auxiliary use due to large size, deep draft and probable high cost in relation to a small monohull.
Single Hull SWATH (S^4) Remote Operated Vehicle	1. No onboard crew. 2. Good stability in heavy seas. 3. Long endurance. 4. All required technologies available.	1. Significant development cost. 2. Deep draft. 3. Total system has not been demonstrated before. 4. Requires high reliability subsystems and expert maintenance.	This design offers an attractive approach to a long endurance auxiliary which can survey moderate to deep depth waters. These units would be small enough for easy handling and and storage aboard a moderately sized mother ship.

Table 2. Auxiliary craft concept summary (continued).

Remotely Piloted HSL	1. No onboard crew required. 2. Technologies available. 3. Shallower draft (2 feet) than S^4 RPV.	1. Not advisable for shallow or congested areas. 2. Requires high reliability subsystems and expert maintenance.	Same as above, except the design would be somewhat more limited in sea state capability but it could operate in shallower water.
Free Swimming Submersible (preprogrammed)	1. Small size allows many to be carried on an operation. 2. By operating many at once, allows increased area coverage rate. 3. Stable operation in high seas.	1. Significant development required to provide necessary reliability. 2. Dependent on several advanced technologies, e.g., propulsion, navigation, control. 3. Potentially very high cost.	The concept is attractive but depends on an advanced level of technology. These technologies are available, but will require development for the application. Cost will be high.

Since the objective of this study was to investigate advanced concepts for an improved hydrographic survey system, the concepts based on the existing survey ships, the LSD and a smaller monohull survey ship are not addressed. In the authors' opinion they do not offer the potential of a significant improvement over the existing operational capability. These ships could be combined with the new auxiliary concepts but would still suffer the sea state limitations for launch and recovery. Only the advanced concepts are discussed further. Both hydrofoil and the surface effect ship were also discarded as potential ship candidates for the reasons stated in table 1. As in the concept tables, the concept discussions are broken down into mother ship and auxiliary craft.

MOTHER SHIP

Of the concepts listed in table 1, the SWATH concept would provide a significant increase in operational capability while reducing ship size and equivalent or improved seakeeping capabilities.

SWATH DESCRIPTION

The SWATH ship (figure 4) hull form embodies two relatively large submerged hulls attached to an above water, box shaped platform by two or four relatively thin streamlined struts. The main features of this design are its superior motion characteristics and reduced drag at cruise speed.

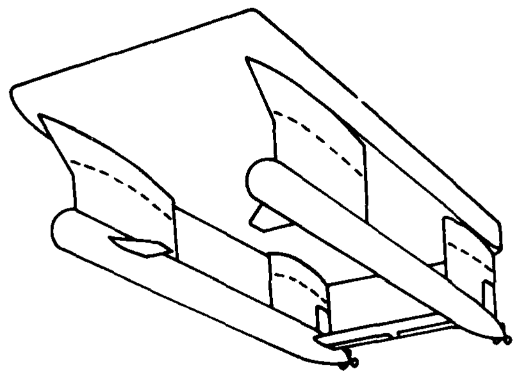

Figure 4. SWATH hull form.

Some features which make this concept attractive for a hydrographic survey or oceanographic ship are its greatly reduced motion in waves, large deck area and internal volume, possible inclusion of a central well, ease of installing underwater sonar and viewing ports, and its adaptability for handling helicopters and various kinds of surface and subsurface vehicles or devices such as HSL's and side looking sonars.

The reduced motion in waves is due to a number of factors, the primary one being the small waterplane area, which minimizes buoyancy changes as waves pass. The aft stabilizing fins provide dynamic stability at moderate-to-high speeds and act together with the smaller forward (canard) fins to provide sizable damping, which significantly reduces ship motion in waves. The optional use of automatic control can further reduce pitch, heave and roll motions at moderate speeds and above, especially in large following waves where motion at high speed without automatic control can be significant.

Maneuverability is good at all speeds. The widely-spaced propellers provide excellent control when docking or stationkeeping. They also improve reliability since the craft will operate on one propeller with negligible yaw and with only about a 7-degree rudder deflection, as is the case of the KAIMALINO (reference 2). Maneuverability at the higher speeds is also good, owing to the spacing between fore and aft struts and the relatively large rudders. Cross-structure impact in waves can be minimized by trimming the control surfaces so that the craft "flies" at the optimum height in a particular sea condition. In the case of automatic control, the trim would be continuously changed to minimize impacts. Impacts in extremely large waves can be reduced further by following the wave contour. Since drag changes vary little in waves and impacts can be minimized, full speed can be sustained in most wave conditions.

The SWATH ship concept has been validated for small craft by the Navy's Semi-Submerged Platform (SSP) KAIMALINO (figures 5 and 6), a 200-ton displacement craft operated as a range craft and SWATH test craft by the Naval Ocean Systems Center (references 2, 3 and 4). Several other SWATH type ships have been built. The Mitsui Engineering and Shipbuilding Company in Japan has constructed a 446-passenger (117-foot-long) ferry, the MESA 80 (figure 7 and reference 5). The Netherlands Offshore Company has constructed a 1400-ton SWATH for use as an offshore supply boat in the North Sea (figure 8). Reference 6 provides a historical background on SWATH ships and a review of the parametric design relationships.

The capabilities and potential of semi-submersible ships (the commercial cousins of the Navy's SWATH concept) is attested to by their use as drill platforms and work platforms in the offshore oil industry. The offshore semisubmersibles are large, in the 15,000- to 25,000-ton displacement range, and are not required to transit long ranges at high speed. They are required to operate reliably under severe sea conditions.

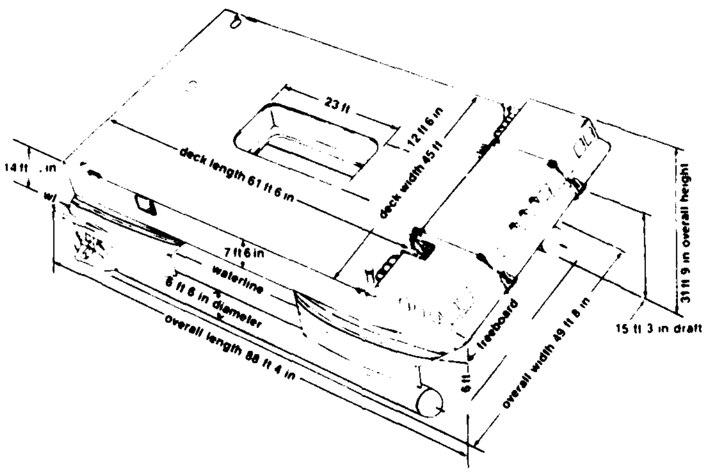

Figure 5. KAIMALINO sketch with dimensions.

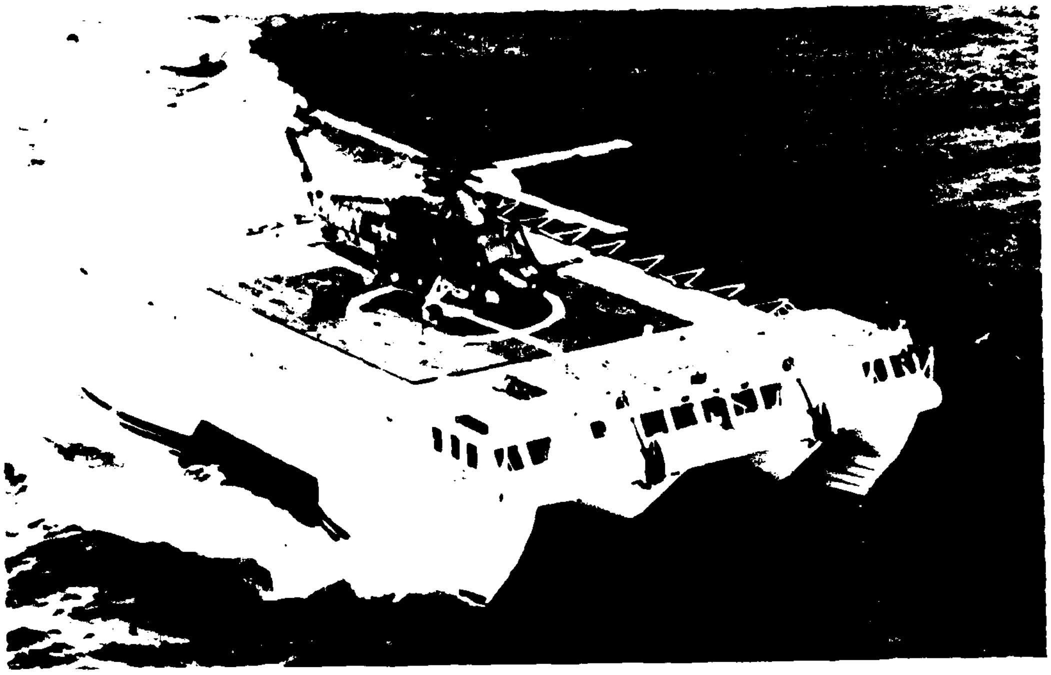

Figure 6. SSP KAIMALINO.

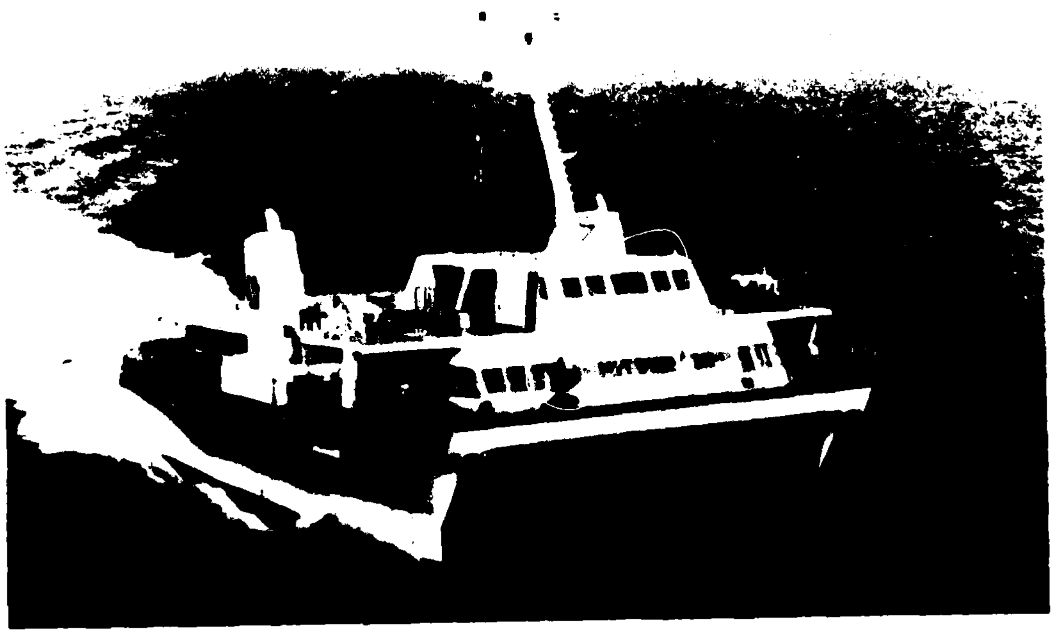

Figure 7. MESA 80 (Mitsui Engineering and Shipbuilding Company).

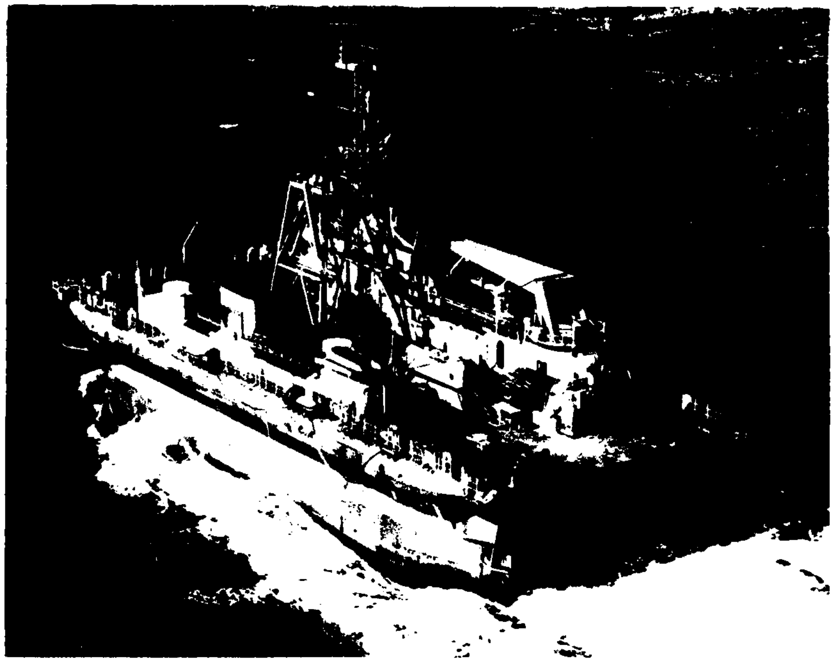

Figure 8. 1400-Ton DUPLUS (Netherlands Offshore Company).

MOTHER SHIP CONCEPT DEVELOPMENT ASSUMPTIONS

All of the concepts for improved hydrographic survey mother ships assume that the best available navigation, data handling and data processing technologies will be utilized. The ship's systems will be designed for efficient operation with minimum sized crews by utilizing the automated control and monitoring system technology and commercial shipping hardware as best demonstrated by modern super tanker design and operational practice. The design concepts are based on the following subsystem approaches.

Navigation

By the time any new survey system becomes available, the Global Positioning Satellite (GPS) system will be operational (FY 1988-1989). This system will utilize synchronous satellites and, utilizing the military navigation channel, will provide geodetic position to within ten metres anywhere on the earth's surface. Use of GPS will significantly decrease the problems and time involved with the current navigation system; e.g., shore stations, politics, supplies, reliability, manpower, etc.

Data Handling

The new survey ship will utilize fully automated data handling. Data collected onboard the HSL-type craft would be processed and verified in real time by a microcomputer onboard the HSL, and it would also be recorded on tape. The HSL track would be plotted in real time with depth data on the track sheet. The computer could also provide the pilot with a course to follow. Modern mini-computers and plotters onboard the mother ship would monitor and analyze the mother ship data in real time. They would also be able to process the HSL's recorded data.

Shallow Water Survey

Maximum use will be made of high-area-coverage-rate, shallow-water survey systems such as laser scanners, multi-spectral scanners, photogrammetry, etc., supported by the shipboard helicopter and land-based survey aircraft. Utilizing these systems to maximum benefit and for reconnaissance should reduce the requirement for the slow HSL near-shore surveys and allow efficient planning of the HSL operations before they are initiated in areas where only very qualitative data are obtained from the airborne systems.

MOTHER SHIP CONCEPTS

Based on the SWATH as a platform, three conceptual hydrographic mapping ship systems have been synthesized. Table 3 provides the major parameters of each system. Each concept is based on a minimum operating range of 4,000 miles at 14-knot cruise speed. All candidate systems are capable of helicopter support and vary primarily in the type of HSL craft being carried. Each craft carries a minimum of two HSL's and has the added capability of supporting towing operations of relatively large sonar bodies for coarse, large area mapping. It must be emphasized that these designs are very preliminary and do not represent the results of a detailed design effort.

Table 3. Conceptual hydrographic survey ship characteristics.

	550 ton	650-700 ton	1000 ton
Length	144 ft	157 ft	175 ft
Beam	69 ft	76 ft	80 ft
Draft	18 ft	19 ft	21 ft
Payload	140 tons	160 tons	240 tons
Range (14-knot cruise)	5,000 nm	5,000 nm	5,000 nm
Power (16-knot top speed)	3,000 hp	3,600 hp	4,800 hp
HSL Capability	four 28-ft HSL's	two 50-ft HSL's	four 50- to 60-ft HSL's
Crew & complement	58	62	90-100

NOTE: These data are representative of potential designs only.

550-Ton Platform

This system (figure 9) will support from two to four upgraded 28-foot HSL's. The 500-ton SWATH is the smallest size SWATH commonly felt to provide an all weather, long range capability. The 550-ton design is based on a 500-ton design (reference 7), but has been upgraded slightly to allow additional fuel capacity and use of a hydrodynamically more efficient lower hull form. This ship would have a cruise speed of 14 knots. It would be 144 feet in length and have a draft of 16.5 feet. This size ship would require a crew of about 18 men and be capable of supporting 30-40 additional oceanographic and scientific personnel. Based on HSL crews of six men each, the ship's crew capacity limits the number of HSL's which can be fully supported to a greater extent than the ability of the mother ship to carry more boats. Table 4 provides a tentative crew breakdown. Figure 10 shows a possible internal arrangement which was derived from the 500-ton design of references 7 and 8. Table 3 provides tentative craft characteristics.

The upgraded 28-foot HSL is essentially the aluminum survey launch used by National Oceanic and Atmospheric Administration (NOAA). It is more rugged, faster, and requires less maintenance than the present Navy launches. It has provided good service.

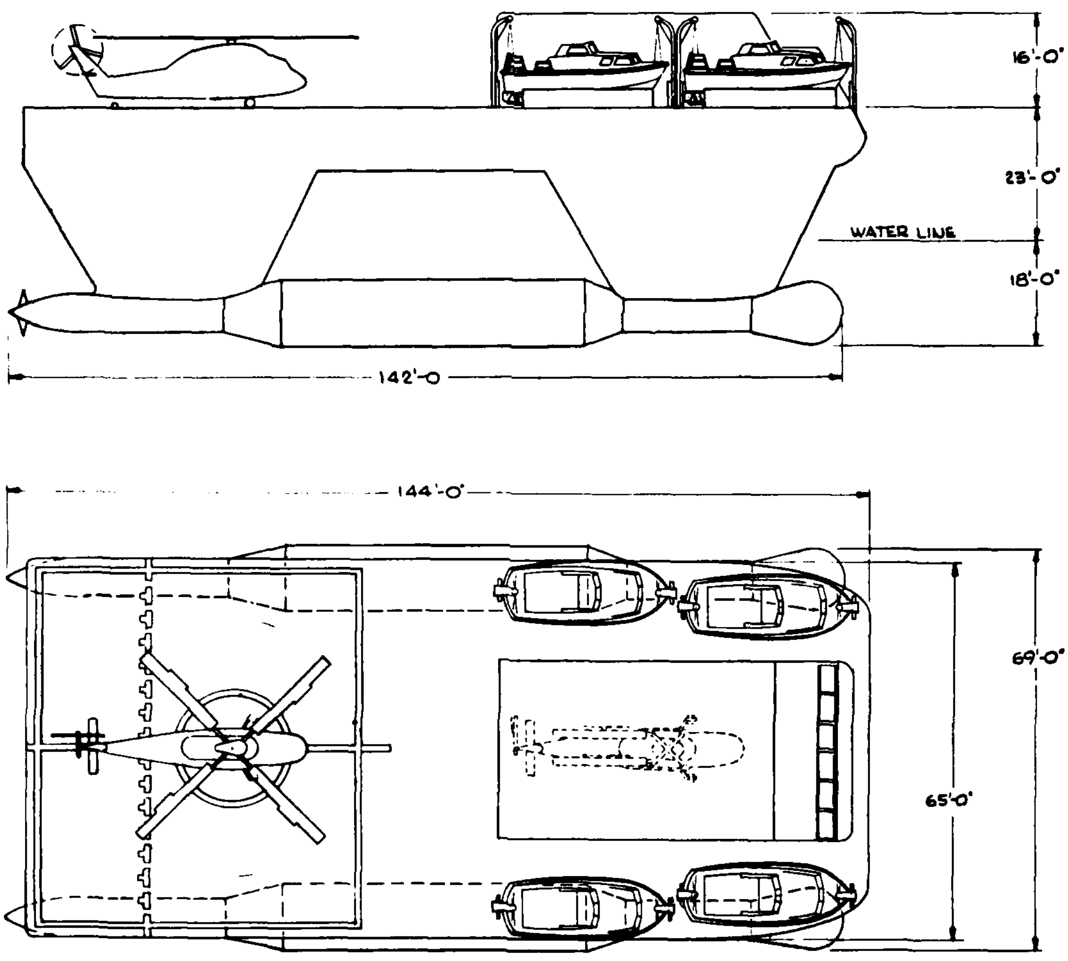

Figure 9. 550-Ton SWATH hydrographic survey ship concept.

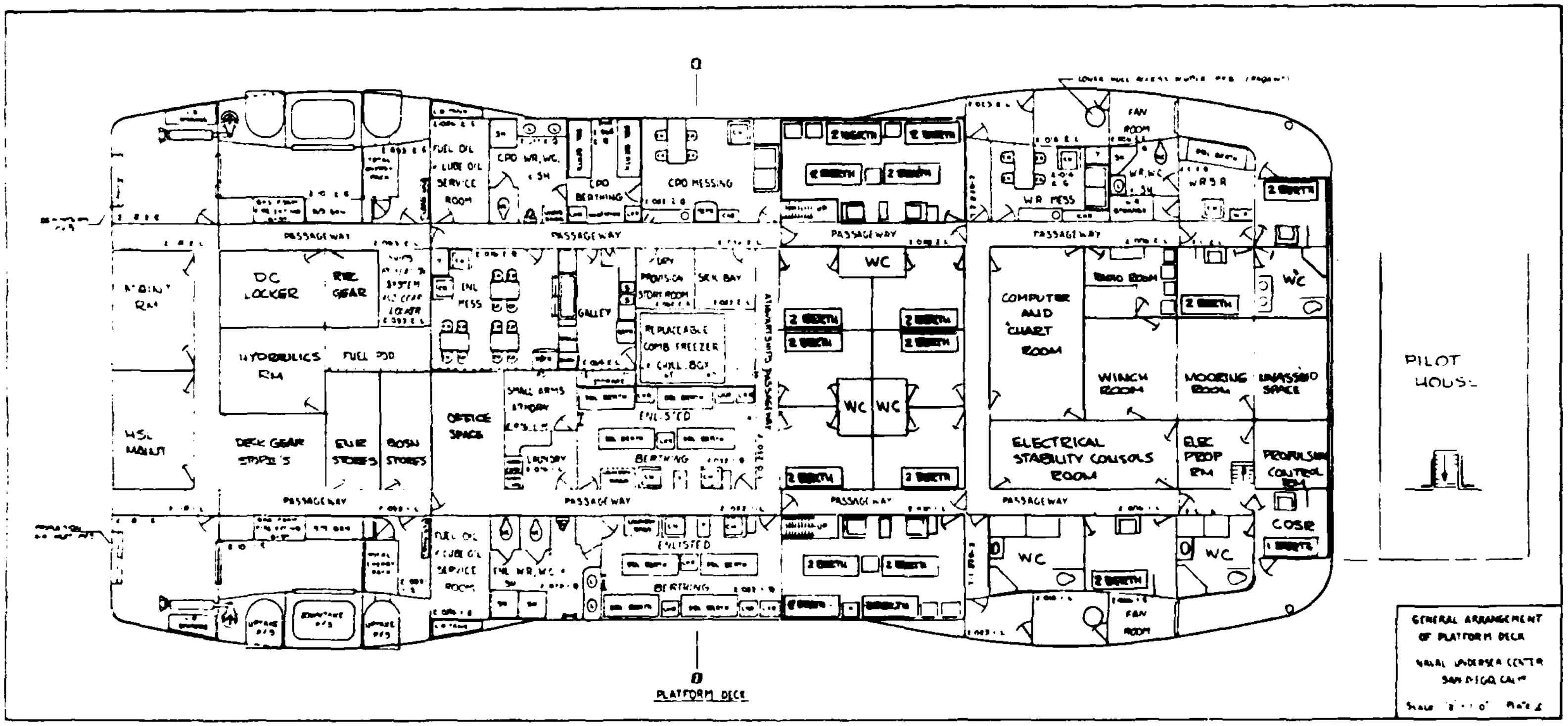

Figure 10. Possible internal arrangement for 550-ton hydrographic survey ship.

Table 4. Manning estimate for 550-ton hydrographic survey ship.

Ship's crew		18
HSL crew, 6 men/boat x 3 boats		18
Helicopter Detachment		14
Oceanographic Staff		8
	TOTAL	58 men

650-Ton Platform

Since the time spent in supporting HSL operations cuts significantly into the survey time available to the mother ship, there is good reason for going to a larger HSL capable of self-sustained operation for several days at a time under reasonable sea conditons, sea state three or less. A 50-foot long HSL displacing approximately 18 tons is felt by most survey personnel contacted to represent a reasonably sized survey launch. To support two of these craft and their crews, a SWATH displacing 650-700 tons is required. Figure 11 shows a concept drawing of this design. Crew requirements for this size vessel are on the order of 20 men. An additional complement of 42 people can be accommodated aboard the ship for supporting the survey mission. A manning estimate is given in table 5.

Table 5. Manning estimate for 650-ton hydrographic survey ship.

Ship's crew		20
HSL crew, 10/boat x 2 boats		20
Helicopter Detachment		14
Oceanographic Staff		8
	TOTAL	62 men

1000-Ton SWATH

A 1,000-ton SWATH survey ship was also considered. This size is attractive from the standpoint of comfort and HSL support capability (four 50-foot HSL's). Table 3 provides the preliminary statistics on this design. The disadvantage of this ship is that it appears to be an overkill in both size and single platform capability. The requirement for supporting four large HSL's would need justification before the additional cost and size of the unit platform could be warranted.

The advantage of this size system would be the utilization of four 50-foot HSL's in parallel operation with the mother ship. The HSL's could operate in the coastal area and the mother ship would survey in deep water. Based on the modeling techniques described in the next section, this system could provide a 25-percent increase in area coverage over the 650-ton system if the HSL's operated 10 hours per day, or a 46-percent increase in area coverage if the HSL's were more heavily manned and operated for 20-24 hours per day. The significant question with this approach would be the efficiency of this type of boat over an extended period encompassing the normally expected sea conditions, and possibly of greater importance, the efficiency and morale of the small boat crews under these extended missions.

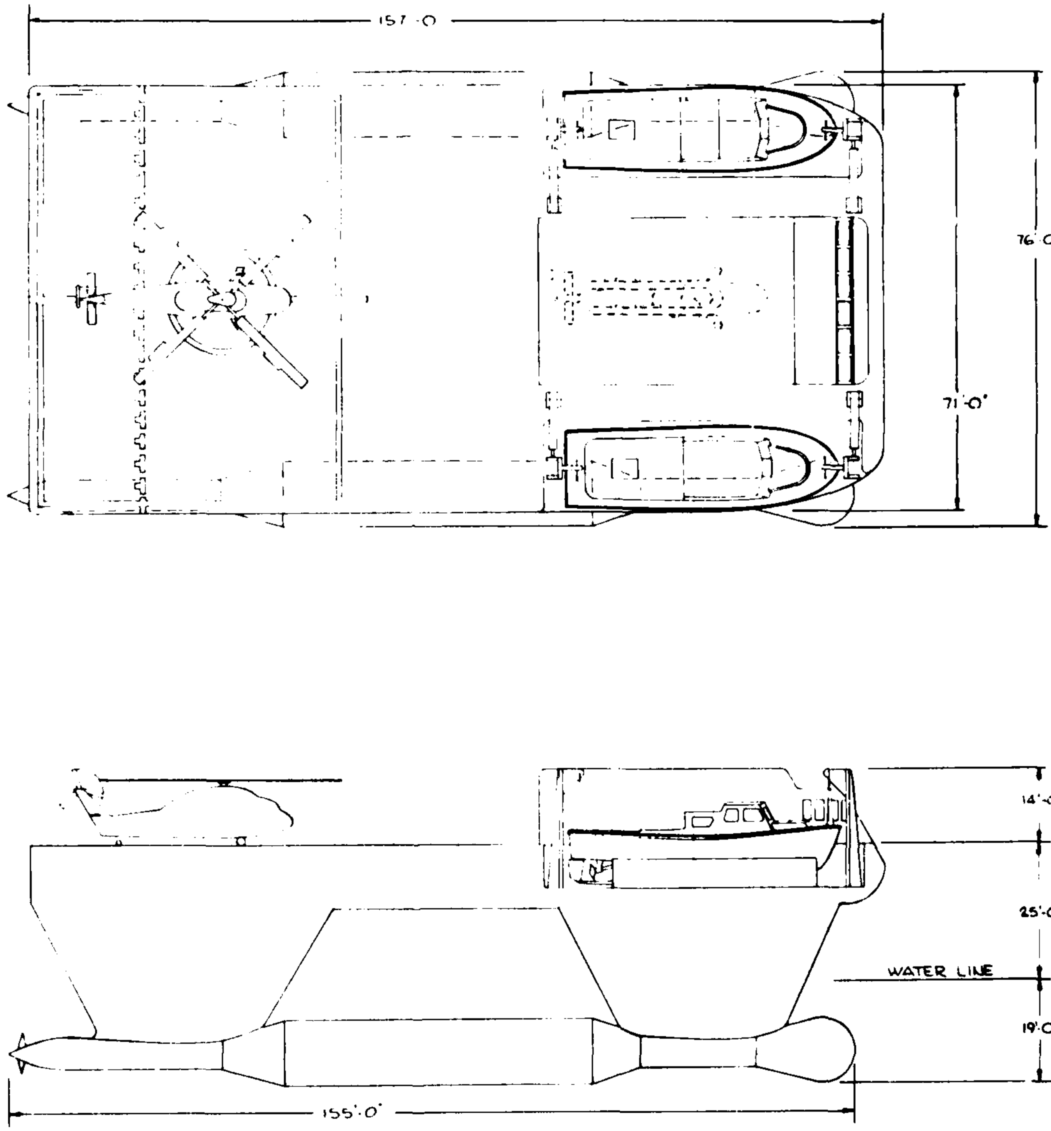

Figure 11. 650-Ton SWATH hydrographic survey ship concept.

AUXILIARY CRAFT CONCEPTS

The concepts investigated for new auxiliary craft include improved manned HSL's and remotely piloted, unmanned systems which would allow a reduction in overall system manning, a reduction in auxiliary size and operation in higher sea states. The requirement for a manned HSL remains for all systems as long as the requirement for near-shore shallow water surveying remains. At the present time, using state-of-the-art or near state-of-the-art technologies, it is not believed that a remotely piloted vehicle can be built which can reliably operate in this environment.

NEW HYDROGRAPHIC SURVEY LAUNCHES

Three manned survey launch designs were considered. Each is discussed below.

Very Shallow Water HSL

For operation in shallow water and near shore, a small, shallow draft, maneuverable, low-cost boat is desired for obstacle avoidance. The 28-foot, aluminum hull hydrographic survey launch used by the National Oceanic and Atmospheric Administration appears ideal. It has been shown to be rugged and reliable, and it requires little maintenance. The boat is limited to daylight operation, but its primary mission, shallow water operation, dictates this in any case. A larger boat capable of several-day operations would be restricted in shallow operations due to its deeper draft and larger mass, which combine to reduce maneuverability and increase the probability of damage. Equipment carried onboard the HSL would include a vertically stabilized fathometer, a GPS receiver and a data processing and recording system. The data processing and recording system would be designed to be operated and monitored by one man. It would record the water depth and coordinates of each sounding point on magnetic tape for future processing on the mother ship. The system also would be designed to provide the HSL crew with a real-time CRT display or plotter of navigation track and bottom profile for verification of the data being collected. Crew size for the 28-foot HSL would be three to four men per boat.

Extended Endurance HSL

Since the overhead time required to support HSL operations, e.g., launch, retrieval, navigation calibration, is significant and represents non-surveying time for both the mother ship and HSL, there is good reason for making the HSL larger and capable of self-sustained operation for several days at a time. Discussions with personnel involved in hydrographic survey work indicate that from experience a 50-foot long HSL is about the minimum size boat that could provide this capability. This boat would displace about 18 tons, have a beam of approximately 15 feet, and require a crew of 8-10 men for continuous operation. Due primarily to crew limitations, operations over extended periods probably would be limited to sea state three or less.

The survey equipment onboard the boat would be nearly the same as that described for the 28-foot HSL. To avoid lost time as a consequence of faulty equipment, redundant data recording and a full complement of spare components should be carried onboard the HSL and one crewman should be trained in field servicing and maintenance.

SWATH Hydrographic Survey Launch

A 50-foot SWATH design HSL was considered briefly. The SWATH has the advantage of greater crew comfort due to its low response to seas. It has the disadvantage of having a relatively deep draft (7-10 feet) considering the mission of the HSL, and its construction costs would most likely be somewhat greater than a monohull of comparable size. Another significant disadvantage of a SWATH HSL is its beam and displacement (approximately 32 tons), which would require a larger mother ship for support.

REMOTELY OPERATED SURVEY CRAFT

Three concepts were generated for remotely operated, unmanned survey vehicles: a preprogrammed submersible; a preprogrammed or remotely controlled single hull semi-submersible vehicle, i.e., a small waterplane area single hull (SWASH); and a drone boat which could be preprogrammed is defined as a system whose mission profile, i.e., survey track, speed, operation, time, etc., is programmed before the operation begins. After being launched, the unit does not require continuous active control by the mother ship's crew during performance of its mission. Remotely controlled refers to active control of an unmanned vehicle via a communications link such as radio by an operator at another location.

Remote operating vehicles offer several potential advantages over the manned survey launch. Removing the crew allows a much smaller hull, operation in higher sea states and extended mission time. Due to their small size, many vehicles could be supported from one mother ship. The disadvantages of remote operating vehicles are their development cost and restriction to areas known to be free of obstacles.

Critical Technologies

Recent advances in the state-of-the-art of propulsion systems (energy storage and conversion), microelectronics and navigation make the long-range unmanned submersible concept an alternative. This type of system is attractive for hydrographic survey due to its independence from the ocean's surface conditions and its relatively small size.

Propulsion System Technology

Figure 12 shows a conceptual remote submersible hydrographic survey vehicle. This vehicle is presented as an example only and is not suggested as being optimum. It would have a range of 240 nm at 10 knots and carry the required navigation and data recording equipment to support the survey mission. The primary technology allowing this increase in range is the energy storage system. Reference 9 provides a comprehensive discussion of the state-of-the-art. Table 6 provides a summary of the more promising state-of-the-art or near-state-of-the-art energy storage systems. In the past, the silver oxide-zinc battery has been the highest energy density secondary system readily available. It also represents a very high cost and short lived system in terms of number of charge/discharge cycles (typically 20-30) possible on a set of batteries.

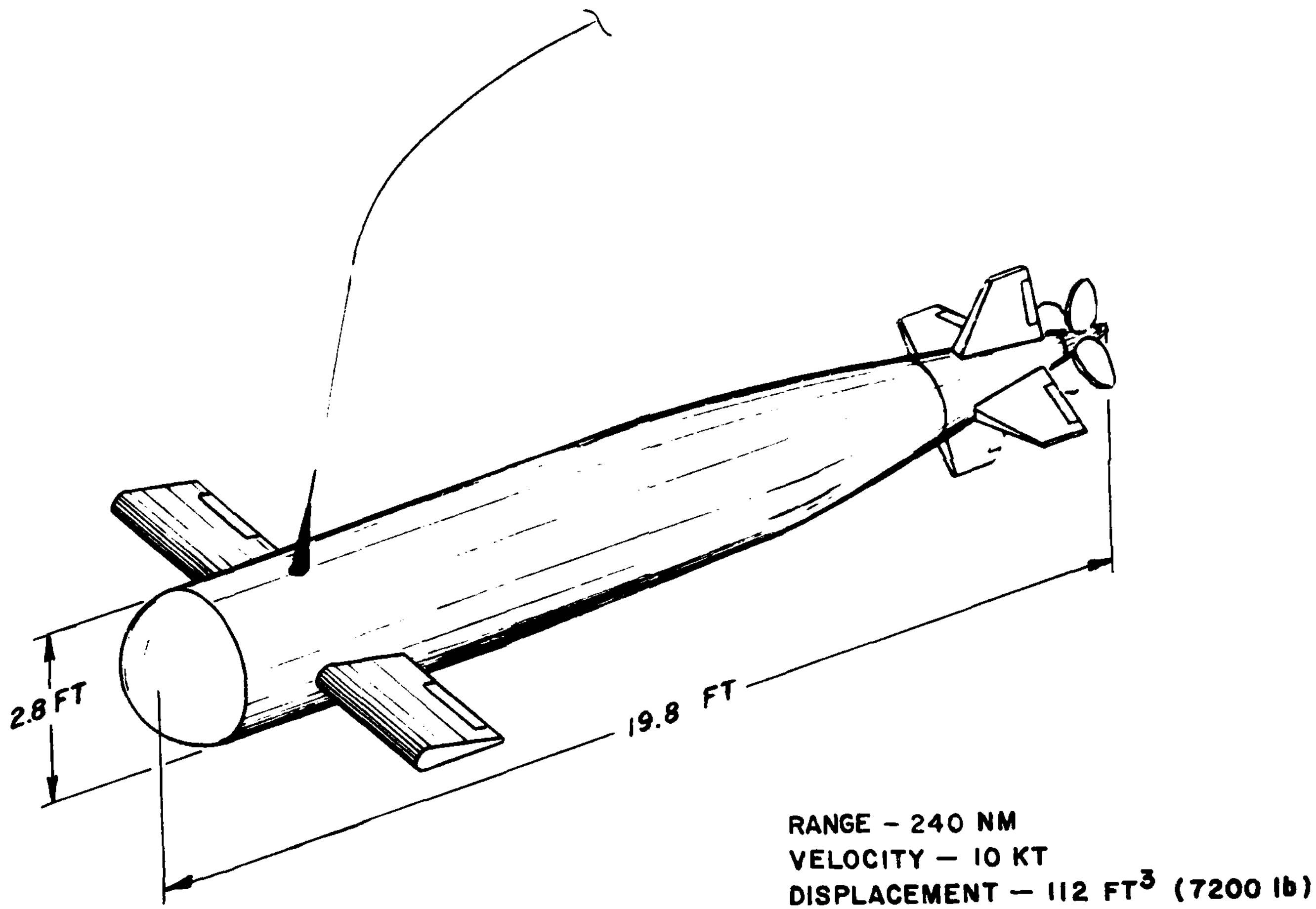

Figure 12. Remote hydrographic survey submersible.

Table 6. Comparison of representative power systems at 10-kW output for 10-hour mission*.

Power Converter	Energy Source	Power Converter W/kg	Power Converter W/litre	Overall System Wh/kg	Overall System Wh/litre	Consumables Kg/kWh	Consumables litres/kWh	Operating Cost, $/kWh
Electric Motor	Advanced Lead-Acid Battery	1298	3846	48	118	-	-	0.64
	Lithium-Thionyl Chloride Battery	1298	3846	412	758	510	900	188
	Fuel Cell, Cyrogenic H_2O_2	1298	3846	1000	588	0.37	0.85	0.12
	Flywheel/Generator	1298	3846	41	47	-	-	0.05
Closed Brayton	Li-SF_6 Combustor	385	435	629	700	0.86	1.1	8
	Sensible Heat	385	435	115	37	-	-	0.12
	Nuclear	385	435	141	303	-	-	
Organic Rankine	Li-SF_6 Combustor	1160†	698†	322	272	1.8	2.3	16
Stirling	Li-SF_6 Combustor	476	833	470	544	0.92	1.2	8
Open Cycle Piston	Otto Fuel	362	1470	135	170	6.0	4.9	15.0
Open Cycle Turbine	Hydrazine Fuel	931	802	167	166	4.9	4.9	23
Closed Cycle Diesel	Diesel Fuel	37	27	125	71	18		4.0
Air Breathing Diesel	Diesel Fuel	59	42	495	357	0.27	0.34	0.037
Air Breathing Gasoline	Gasoline	93	84	758	662	0.20	0.27	0.036
Air Breathing Gas Turbine	JP4, JP5 or Diesel Fuel	448	194	855	681	0.63	0.79	0.072

*Table from Reference 9.
†Data based on 30-kW system.

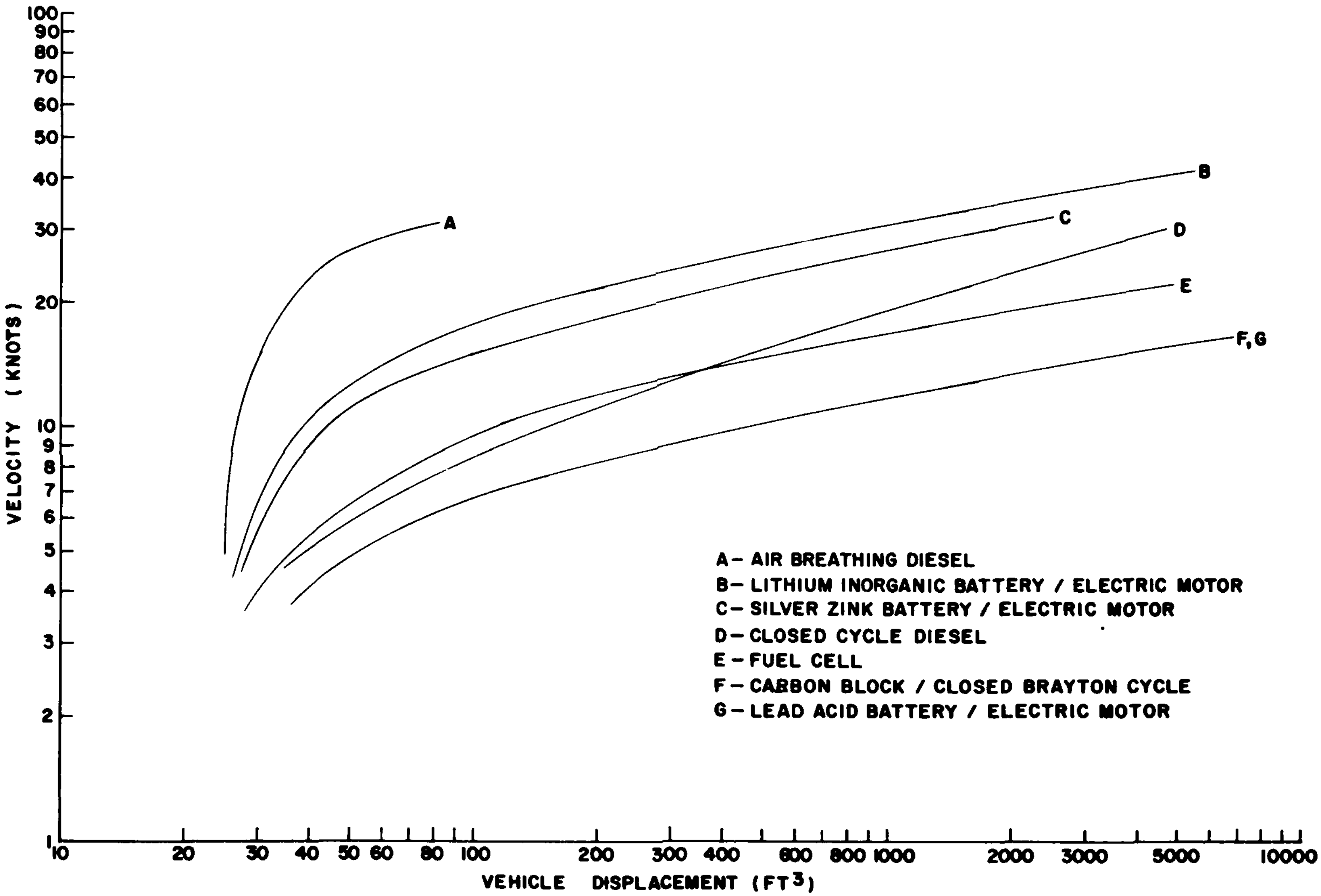

Figure 13. Velocity vs displacement graph for various power systems.

Recent work by the Navy and industry on lithium inorganic batteries, closed Brayton cycle (CBC) engines using chemical combustors or sensible heat storage, fuel cells and closed cycle internal combustion, e.g., Wankel and piston, have expanded the viable alternatives significantly.

The energy storage systems considered for the survey vehicle include the lithium inorganic battery, H_2O_2 fuel cell, the carbon block (sensible heat storage)/Brayton cycle engine and the closed cycle diesel engine system. For a range of 240 nm the displaced volume of a vehicle as configured in figure 12 is shown in figure 13 as a function of velocity and propulsion system type.

The figure shows the dramatic effect of both velocity and propulsion system specific energy (energy stored per unit volume) and specific power (power per unit volume). The lead acid battery and closed Brayton cycle systems fall nearly on the same line in this example. The Brayton cycle system uses a heated graphite block for energy storage and suffers in terms of volume due to the relatively low efficiency of the CBC engine in relation to electric motors. The lead acid battery suffers from low specific energy and high weight. For long endurance closed sytems it is best to strive for high specific energy and high conversion efficiency for minimum vehicle size.

The lithium inorganic battery is presently undergoing intensive development supported both by industry and the government. This sytem provides the smallest vehicle for the conditions prescribed. The major drawback to this battery is that it is a primary cell, i.e., it cannot be recharged. This would preclude its use from the survey mission which must also be cost effective.

The H_2O_2 fuel cell utilizing high pressure gas storage is attractive for the survey mission. It offers small size with available technology and relatively low cost operation. An H_2O_2 fuel cell currently powers the Navy's Deep Submergence Rescue Vehicle (reference 9). Both hydrogen and oxygen could be produced onboard the mother ship.

For comparison purposes, figure 13 includes an air breathing diesel. It can be seen that, if at all possible, an air breathing, i.e., surface system should be used due to high energy density and available technology.

Vehicle Control

The control of the remote vehicle would be performed by an onboard microcomputer preprogrammed to follow a prescribed navigation grid and by an acoustic command link to the mother ship. Inputs from an onboard navigation system would continuously update the vehicle position to the computer. The computer would also be programmed to handle contingency situations and process and monitor the bathymetry data prior to storage on magnetic tape. A low-data-rate acoustic telemetry link would provide status updates to the mother ship and allow program updates back to the vehicle. A very reliable acoustic system was developed for Under Ice Arctic Research Submersible (UARS) (reference 11), which was developed by the Applied Research Physics Laboratory of the University of Washington. For surface or near surface vehicles, an RF telemetry link could provide real time control or program updates.

Navigation

Two navigation systems are available which could satisfy the critical requirements of a remote submersible survey system: the Electrostatic Gyro Navigator (ESGN) being developed by North American Rockwell and the doppler inertial navigator developed at the Naval Coastal Systems Center for use on the MK7 and MK9 swimmer delivery vehicles. The performances of both systems are classified, but either can meet the requirements of the survey vehicle if refreshed from the GPS system during periodic surfacings. Based on cost, reliability and hardware volume, the doppler inertial system would appear to be the system of choice for the survey vehicle.

Remote Submersible

Remotely piloted submersible (RPS) vehicles have been utilized for some time in several missions. They have been used, for example, as acoustic targets for submarines (MK27 and MK30 targets) and in under ice surveys (the UARs). The submersible vehicle could remove the influences of weather and sea state from the performance of the auxiliary vehicles survey mission but would remain tied to weather during launch and recovery operations.

This vehicle concept is shown in figure 12. It has been sized utilizing the H_2O_2 fuel cell electric propulsion system. The system would be slightly positively buoyant, operate at a depth of 50-100 feet below the surface and have a range of 240 nm at a speed of 10 knots. Figure 14 shows the effect of changes in speed on the range of this design.

Operational Scenario

A possible mission scenario for the RPS follows:

(1) Charge fuel tanks, input navigation path and perform system checkout onboard mother ship. The checkout function would be completely automated and mini-computer controlled.

(2) Launch - the RPS could be launched simply by sliding from the mother ship.

(3) Mapping - From the standpoint of efficiency, ability to handle possible contingencies quickly and minimization of transit time to the launch and retrieval areas, the positioning of the survey craft shown in figure 15 has much to offer. In this configuration several RPS's are launched and swim parallel to the survey track of the mother ship at a specified lane spacing. This arrangement allows for:

- Immediate access to the vehicles in the event of a malfunction.

- Direct communication with and control of the vehicles during an operation via an underwater acoustic data transmission system for status monitoring and control system override or update. The UARS (reference 10), utilized an acoustic telemetry system at ranges up to 3,000 yards under ice.

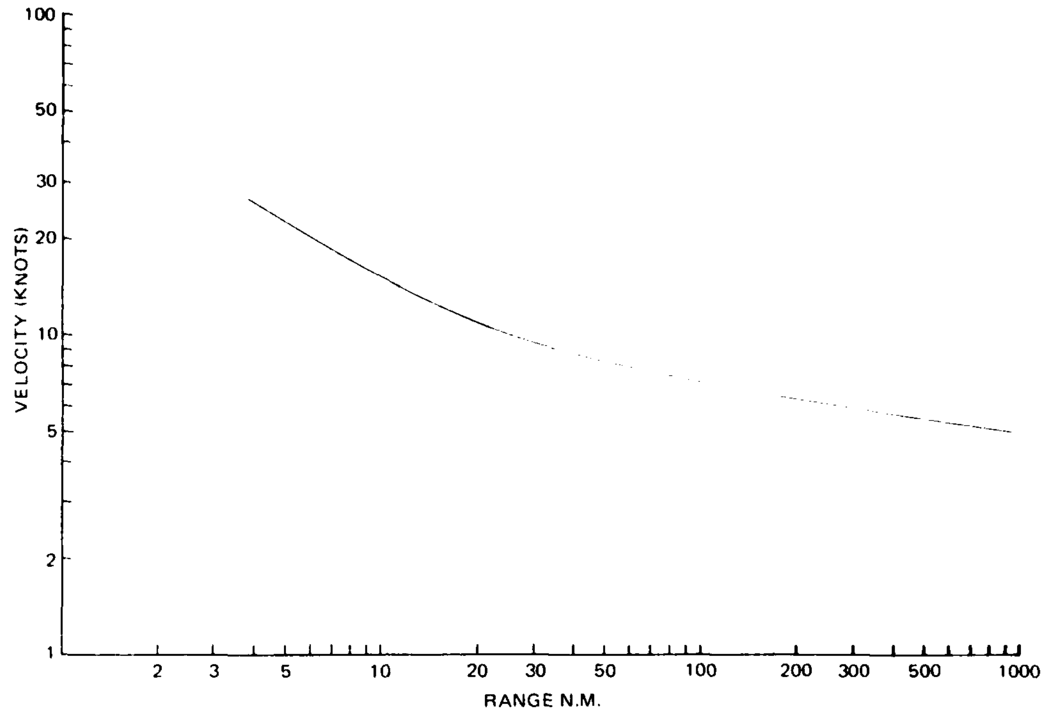

Figure 14. Graph of range of remote submersible vs velocity.

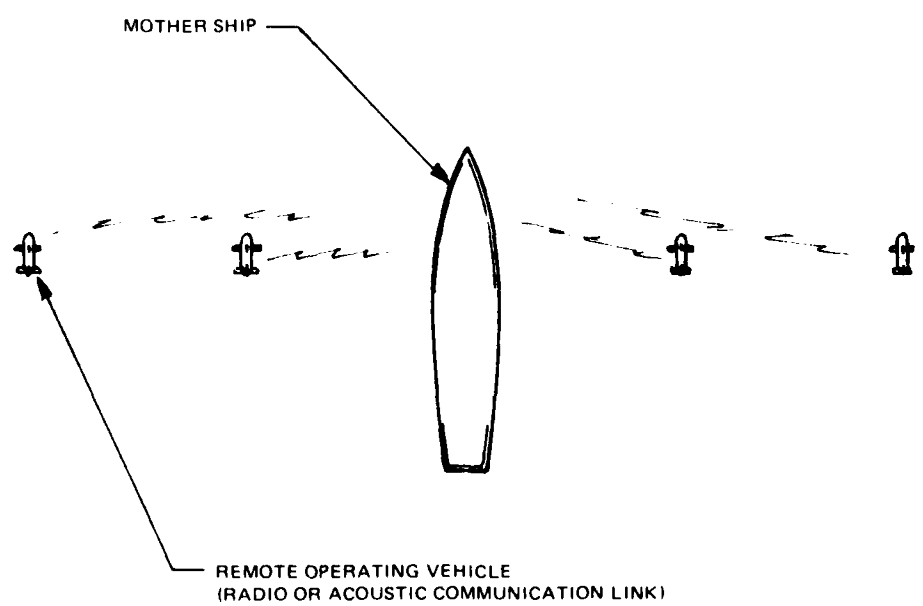

Figure 15. RPV survey scenario.

- Near-real-time verification of data at present cross check points via the acoustic telemetry system.

(4) Navigation - The remote submersible navigation system would self-calibrate from an onboard GPS receiver. The vehicle would come to the surface at preset time intervals, based on measured system drift rates, and re-establish its datum.

(5) Recovery - At the end of its mission the submersible would come to the surface, go dead-in-the-water and activate its location equipment, i.e., strobe light, R. F. beacon and acoustic pinger. The attachment of recovery lines from the ship could be made to a lift bale or structure on top of the unit.

Vehicle Support

A fleet of four remote submersibles would require four to six skilled technicians for maintenance and upkeep. Much of the preoperation checkout and programming function could be done by a computer on the mother ship. This is presently being done to a limited extent with the MK30 targets. Design of the remote submersibles would be modular for efficient repair through replacement of modules.

Single Hull Semisubmersible RPV

A concept drawing of a semisubmersible hydrogrpahic survey craft is shown in figure 16. Except for its hull form and propulsion system, this concept is similar to the remote submersible described previously. This vehicle is significantly larger than the minimum size derived from figure 13 to provide reasonable response in large seas.

The semisubmersible hull form has shown potential for providing good seakeeping, low response to waves and low drag (reference 1). This design is ideal for a hydrographic survey auxiliary since it allows use of an air breathing diesel engine, direct radio communication with the mother ship and direct, full time access to the GPS for continuous navigation.

The operation of the Remotely Piloted Vehicle (RPV) would be similar to the remote submersible except for the real time high data rate communication capability and full time use of GPS. The semisubmersible could be controlled full time by an operator on the mother ship, but it would be much more efficient to preprogram its course and correct it as required over the RF link.

The survey approach of swimming the semisubmersible on a parallel course with the mother ship is applicable with this system for all of the reasons stated in the previous section. To maintain reliable radio contact, the RPV's should stay within line-of-sight distance of the mother ship.

From the standpoint of cost, operational risk and utilizing low-risk technologies, the single hull semisubmersible is a more attractive concept than the submersible system. The support required for four semisubmersible survey craft would be about the same as for the submersible system: four to six men.

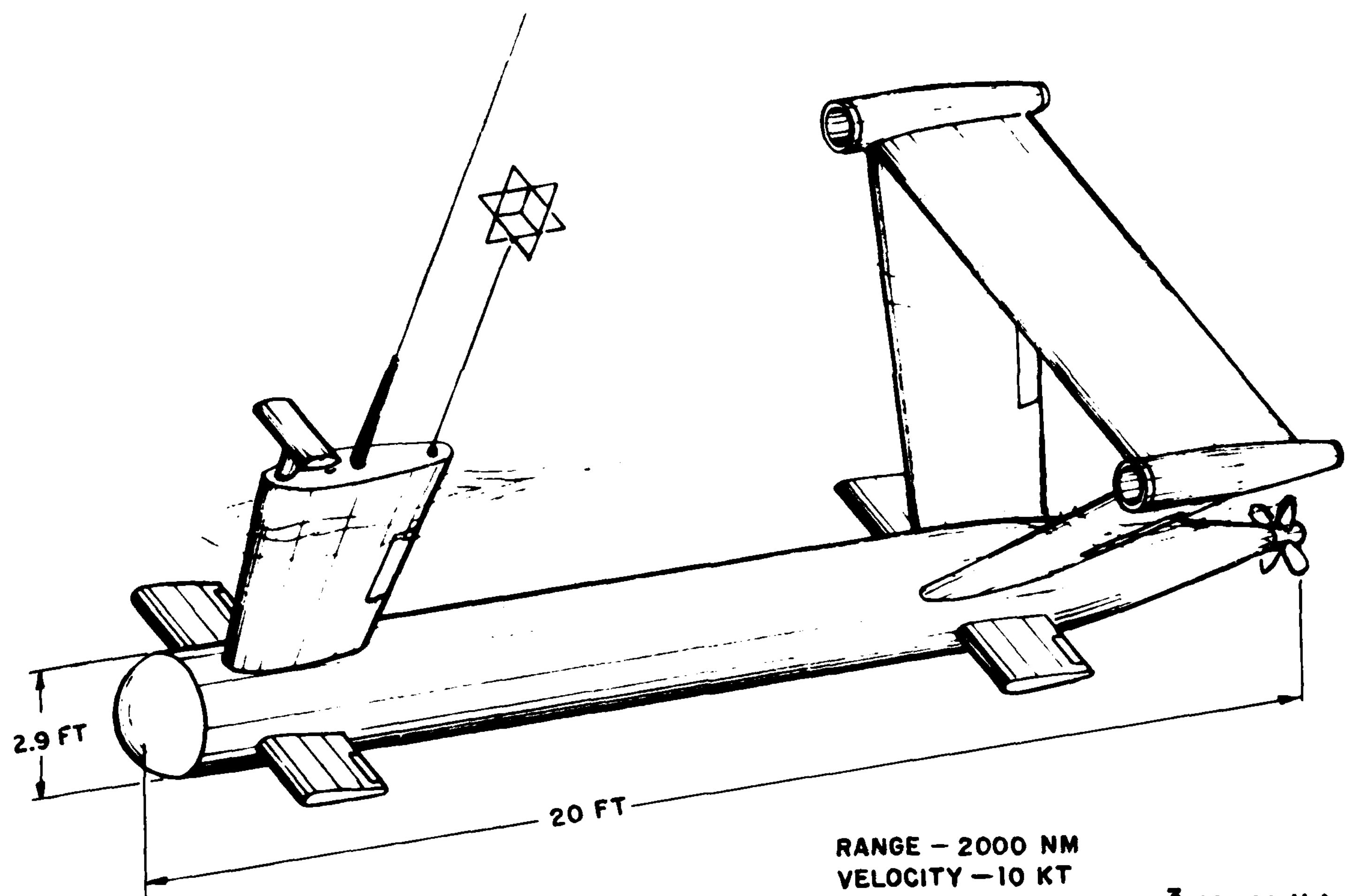

Figure 16. Semisubmersible RPS vehicle.

Drone Boat

The drone boat concept is similar to the previous concept except for the hull form. The boat would be of the HSL type, probably on the order of 20-25 feet long, and would be remotely controlled. Operation would be identical to the semisubmersible.

The boat would have to be of a larger beam than the semisubmersible to provide even modest seakeeping.

The drone boat would be more limited as to maximum sea state than the semisubmersible. From a development cost standpoint the drone boat would be somewhat lower in price than the semisubmersible but would also have more limited capability.

OPERATION MODELING

Based on the continuing requirement for performing shallow water surveys with manned HSL's, a brief analysis was performed to assess the potential gains in area coverage of utilizing larger, more autonomous HSL's in near-shore surveying. The analysis was based on the following common set of assumptions:

(1) There is no down time due to equipment malfunction.

(2) There are no errors or problems with the navigation system.

(3) The navigation system will be the NAVSTAR Global Positioning System. Thus, no time is spent setting up the navigation sites or calibrating the HSL's navigation equipment before and after the daily survey.

(4) The HSL transit speed is 9 knots and its survey speed is 8 knots.

(5) The ship's transit speed is 12 knots and its survey speed is 10 knots.

(6) The HSL survey area is surveyed on a 1:50,000 scale and the ship's survey area is surveyed on a 1:100,000 scale.

(7) The survey is conducted by one ship and two HSL's.

The first of the three cases analyzed was the present method of conducting the survey where the HSL's are recovered at the end of the day. This is used as the baseline. The second case considered a more independent HSL that surveys 10 hours per day and need not be recovered daily. The third case considered HSL's that can survey 24 hours a day. The objective of this effort was to obtain a feeling for the relative improvement in survey rate possible with the higher endurance but larger and more expensive systems.

The present method of survey operation was first analyzed to establish a baseline. In this case, the ship conducts the survey along with two HSL's. Each HSL has a survey time of seven hours during its operating period between 0800 and 1630, and the ship is restricted to not being more than four hours transit time away from the HSL's. Table 7 summarizes the survey mileages and area covered per day for this case. Appendix B describes how these numbers were obtained and the assumptions that were made.

Table 7. Survey mileages per day for baseline case.

SURVEY CRAFT	MILEAGE (miles)	AREA (sq miles)
2 HSL's	116.3	24.0
Ship	240.8	100.0
TOTAL	357.1	124.0

In the second survey model, the operation is similar to the first except that the HSL's are semiautonomous and need not be recovered at the end of the day. The HSL's survey for 10 hours during the day. Table 8 summarizes the survey mileages and the area covered per day for this case. Appendix C describes the survey patterns and the calculation of the mileages.

Table 8. Survey mileages for 10-hour HSL operations.

SURVEY CRAFT	MILEAGE (miles)	AREA (sq. miles)
2 HSL's	177.0	40.0
Ship	259.0	120.0
TOTAL	436.0	160.0

For the third model, the two HSL's are able to survey 24 hours a day and need not be recovered daily by the ship. Table 9 summarizes the mileages for this case and appendix D describes the survey patterns and calculations.

Table 9. Survey mileages for 24-hour HSL operation.

SURVEY CRAFT	MILEAGE (miles)	AREA (sq. miles)
2 HSL's	420.0	104.0
Ship	259.0	120.0
TOTAL	669.0	224.0

As can be seen, the more autonomous the HSL, the greater the total survey mileage that can be achieved by both the HSL and the ship. The HSL can spend more time surveying instead of transiting to and from the ship in order to be recovered. The ship can also spend more time surveying since it does not need to be near the HSL's and does not have to launch and recover them daily.

CONCLUSIONS AND RECOMMENDATIONS

Background work performed as the initial portion of the study has shown that the present survey capability is limited by number of assets, old and unreliable equipment and the high turnover rate of survey personnel. An improved capability can be achieved by:

(1) Utilizing current state-of-the-art equipment and systems for automating data collection and processing and navigation.

(2) Utilizing much smaller survey ships based on the SWATH hull form. These ships would provide the same or improved operational capability with much reduced initial cost and operating cost than the present ships, the CHAUVENET and HARKNESS.

(3) Utilizing the remote sensor systems, when available, for very shallow water surveying or in more turbid areas using their limited data for operations planning.

(4) Utilizing more reliable and efficient Hydrographic Survey Launches (HSL) for near-shore and very shallow water operations.

(5) Possibly utilizing two to four drone single hull semisubmersibles or 50-foot manned HSL's for operating in conjunction with the mother craft for medium, i.e., unobstructed, to deep water surveying.

(6) Reducing personnel turnover rates.

SURVEY SHIPS

New hydrographic survey ship designs should utilize the SWATH hull form. This configuration would provide an improved capability at a much reduced displacement and crew manning requirement.

Three ship concepts were considered as candidates for a new survey system: a 550-ton SWATH supporting four 28-foot HSL's, a 650- to 700-ton design supporting two 50-foot HSL's, and a 1,000-ton design supporting four 50-foot HSL's.

Based on the findings of this study, it is recommended that both the 550-ton and 650- to 700-ton SWATH hydrographic survey ships be further investigated to the point of producing preliminary designs and cost estimates. Prior to the design study, an in-depth, objective evaluation must be conducted to establish the roles of the remote survey sensors and HSL's in shallow survey operations to define the number and size of HSL's required and their mission requirements.

If extensive HSL operations are required, the tradeoff might be between the 650-ton system and the 1,000-ton system.

The 500-ton system has a lower initial cost and could potentially provide greater flexibility due to the alternatives possible with a larger number of units.

Further study must be performed to define the role of the HSL beyond shallow water surveying and the overall requirement in terms of numbers of units.

AUXILIARY CRAFT

Both manned and preprogrammed or remote controlled, unmanned auxiliary craft have been considered. The requirement for a small, relatively inexpensive HSL remains for use in the near-shore shallow environment. For this application, the 28-foot aluminum survey boat used by NOAA or an equivalent appears ideal. Manning of these boats can be kept to a minimum and their operation made more efficient by automating the data recording and navigation functions.

Use of a larger, 50-foot, manned HSL for more autonomous operation from the mother ship shows merit from a survey rate point of view. This assumes that these relatively high value craft can perform the required shallow water and cluttered area surveying at a reasonable risk.

If the 50-foot manned HSL is limited due to risk only to moderate and deep water surveying, then the remote controlled single hull semisubmersible offers a significant potential reduction in manning and an improved operating sea state capability. This improved capability comes at the cost of higher technology development and the attendant demand for increased crew training and proficiency. The 50-foot HSL with a state-of-the-art automated data recording system and navigation system offers a near-term capability with a modest development cost. The real cost of this approach is in the size of the mother ship required to support it, the operational cost of manning it and the limitations on operations time imposed by sea state and human factors.

The remote controlled single hull semisubmersible survey craft represents one to two orders of magnitude greater development cost but a significantly greater potential savings in operating costs due to reduced mother ship size, improved sea state capability and elimination of the human factors problems associated with manning small boats for extended periods. In summary, a cost benefit analysis needs to be performed based on realistic operational requirements and pragmatic assessments of the level of personnel technical capability available to support the operation.

The submersible survey vehicle is not recommended for this application due to its high development cost, potentially another order of magnitude greater than the semisubmersible, and its greater level of technical sophistication.

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APPENDIX A: PANAMA SURVEY, FEBRUARY 1977 – SEPTEMBER 1978

I. Summary of Activities:

The USNS CHAUVENET began the Panama survey with SURVOP 5-77 in February 1977 after transiting from WESTPAC and an inport in Pearl Harbor. The boats began surveying in Parita Bay while the ship began surveying east and south of Punta Mala. Weather and logistics problems hampered HSL operations and equipment and ship's generator problems hindered the ship's work. Many of the problems encountered during this first SURVOP continued to plague operations during the entire Panama deployment.

The next two SURVOPS were highly successful for the ship. However, problems with both Raydist and ARGO systems almost prevented any HSL survey work. Several geodetic points were located and will be used in the future.

SURVOPS 8-77 and 9-77 continued work west of Punta Mala to south of Jicarita Island. One HSL and crew remained in Panama to support the HYSURCH project. SURVOPS 10-77 and 11-77 were conducted in the Punta Burica/Armuelles area. Several casualties in ARGO and Raydist delayed survey on numerous occasions. Repair efforts were frequently thwarted by the lack of spare parts. Periodic problems were encountered by the helicopter and the ship as well. Following SURVOP 11-77 the ship proceeded to New Orleans, LA. for an overhaul which lasted from 3 September to 29 October 1977.

Following a disappointing yard period in which much of the required work was not accomplished due to fiscal restraints, the CHAUVENET returned to Panama with additional requirements added to the survey specifications. SURVOP 1-78 was plagued with problems that prevented the completion of any survey miles. The ARGO system was CASREPT and required the assistance of a Cubic Corporation technician to change the system operating frequency and to make repairs. The HSL's were not operated because of water and fungus in the fuel. SURVOP 2-78 was also relatively difficult due to continued ARGO, Raydist and HSL problems, but significant progress was made by the ship at the end of the SURVOP, again with the assistance of Cubic Corporation technical representatives.

The ship returned to the Bahia Parita area for SURVOP 3-78 and with three HSL's, conducted a successful SURVOP. The Bahia Parita survey was completed during SURVOP 4-78 and the ship then transited to Bahia Pinas to establish a Geoceiver site. The ship surveyed while personnel set up the site and looked for additional control points. The Frailes area was next set up for survey so that HSL work could be completed in that area. This work proved highly successful and after the Geoceiver site was backloaded at Pinas Bay, the ship returned to Rodman.

The USNS DE STEIGUER joined the USNS CHAUVENET in Bahia Pinas during SURVOP 5-78. The HSL's did not survey because of Raydist equipment problems. SURVOP 6-78 was started with a two-boat boat camp remaining in Rodman to survey the approach to the Panama Canal. The ARGO net was then transferred to Bahia De Charco Azul to support the DE STEIGUER survey in that area. CHAUVENET picked up the boats from the boat camp and then returned to Bahia Pinas to conduct the HSL work required there. The ship returned to Bahia Pinas following the inport and completed that area at the beginning of SURVOP 7-78. The CHAUVENET then joined the DE STEIGUER in the survey of the Bahia De Charco Azul area. The DE STEIGUER completed her assigned area and, after a short inport in Rodman, proceeded to San Diego, CA. The CHAUVENET supported the HSL's by establishing geodetic control and setting up the Raydist net. Problems were encountered when the PDP-9 computer went down. The ship was then required to survey using manual plotting techniques. SURVOP 8-78 proved highly successful as work continued in the Bahia De Charco Azul area. This was in spite of the fact that there were only three operational DE-723 fathometers on board. Three HSL's surveyed during the day and at night a fathometer was moved on board the ship for continued survey. SURVOP 9-78 was used to complete the Bahia De Charco Azul area. This SURVOP was highlighted by a highly successful survey of the Pedregal River. Utilizing Raydist and being supported from a boat camp in Pedregal, the river survey was completed in just three days.

Major problems with the ship's service generators restricted the CHAUVENET to Rodman for SURVOP 10-78. The HSL's were used to survey the southern approach to the canal. The SURVOP was highly successful, with another boat camp being established to minimize time lost due to transit. Major damage was sustained by one HSL when it ran aground, damaging the hull and skeg. Upon completion of the south coast, SURVOP 11-78 started with the transit of the HSL's through the canal to begin work on the north coast. A boat camp was established at Coco Solo to support the boats until the ship could arrive. The ship transited the canal and surveyed for about one week before another major casualty forced the ship into port once again. The biggest problem on the north coast was finding suitable geodetic control. Although abundant control was available in the immediate vicinity of the canal entrance, a great deal of confusion existed because of several stations with the same or similar names, in close proximity, based on different datums. Again, however, significant survey work was accomplished before the ship was repaired, transited the canal and then returned to San Francisco for overhaul.

II. Summary of Accomplishments (February 1977 – September 1978).

1. 28,127 miles of ship hydrography data were collected.

2. 9,541 miles of HSL hydrographic data were collected.

3. Completion of the following sheets:

Sheet	SURVOP	Sheet	SURVOP
.001	5-77	.028	6-78
.002	5-77	.029	6-78
.016	9-77	.037	6-78
.017	9-77	.006	7-78
.018	9-77	.007A-D	7-78
.005	10-77	.010	7-78
.009	3-78	.011	7-78
.030	3-78	.044	8-78
.032	3-78	.007	9-78
.033	3-78	.007E-G	9-78
.003	4-78	.021	9-78
.004	4-78	.022	9-78
.014	4-78	.023	9-78
.019	4-78	.042	9-78
.020	4-78	.043	9-78
.031	4-78	.045	10-78
.034	4-78	.045A	10-78
.035	4-78	.046	10-78
.036	5-78	.047	10-78
.012	6-78	H.007D	10-78
.013	6-78	H.012	10-78

4. The following North Coast sheets were surveyed during SURVOP 11-78 as indicated:

Sheet	% Survey Completed
.001	100
.002	75
.003	25
.004	75
.005	90
.006	0
.007	100
.008	100

5. Support was provided to the HYSURCH survey, DE STEIGUER survey, and the HARSAP program.

6. All data and other information collected have been forwarded to NAVOCEANO for completion of processing and evaluation.

7. A field chart showing the Port of Armuelles was produced on board.

III. General Comments and Lessons Learned:

1. Personnel:

The Oceanographic Unit FOUR/USNS CHAUVENET Panama Survey was completed with long hours and hard effort by all. While it is true much of the equipment is in poor condition and obsolete, the big problem in Panama, or for any other operation, remains with personnel. There is a lack of trained people coming to the units and the time for training is nearly non-existent once the survey starts. This was especially true in Panama, due to the short transit and inport times. Efforts should be made to train as many people as possible on pertinent equipment prior to their reporting on board due to the uniqueness of both OCUNITS FOUR and FIVE. One possible way to do this would be to encourage people at NAVADISUPUNIT or NAVOCEANO (WYMAN Support Det) to request duty with the OCUNITS and similarly taking experienced people from the units to these commands.

Another significant problem which began in September 1977 and continued through August 1978 was that a number of key personnel billets were gapped during this period, in some cases for as long as eight months. Requests for personnel in key billets must be coordinated with detailers to make sure reliefs have at least one month for break-in and turnover. The importance of this becomes more evident in the higher supervisory positions such as E-6/E-7, but frequently it is just as important at lower levels for a smooth transition. Direct discussions with detailers did succeed in eventually getting all key billets filled. The recently recommended priority manning for OCUNITS should also help prevent future problems.

Personnel support in Panama itself was outstanding. The Naval Station Panama Canal provided fuel, repair facilities, messing and berthing for the independent boat camps, and provided transportation, medical, dental, disbursing, supply and recreational support during each inport. The Naval Security Group Activity on Galeta Island and the 549th MP Company at Fort Gulick also provided this support on the North Coast. A list of offices and key contacts are in the final section of this appendix.

2. Equipment:

a. Electronics. Without a doubt, the worst equipment problem in Panama was the Raytheon DE-723 FATHOMETERS. Major problems were parts support, alignment of the unit with the rotating arm design, bad fathometer paper, and just old worn out equipment. Naval Station Panama Canal Public Works was able to manufacture some parts upon request.

b. Raydist worked fairly well but again a lack of spare parts for repair was a significant problem. It was also very sensitive to rain storms and hard to calibrate. During the rainy season (April October) rain occurs almost daily. Operations were occasionally hampered by limited visibility in the early morning and by severe thunderstorms in the late afternoon. The day's data had to be calibrated out prior to the storm's arrival or the work quite probably would be lost or at best questionable for that day.

c. ARGO (DM-50) worked very well on the ship except for a sensitivity to movement in the antenna ground field and lightning storms near either the ship or site. Unfortunately, the DM-50 could only be used on the ship, leaving the boats to operate off a separate net. The requirement to establish a separate net for both the boats and ship required twice the geodesy that a single system would require. Some of this lost time was compensated for by the fact that once ARGO was operational it was a much more dependable system than Raydist. Initial deployment of this system was apparently made without sufficient training of OCUNIT personnel. Considerable difficulty was encountered when the system was first deployed in 1977 and could possibly have been reduced if on board personnel had received better training as both operators and repairmen. This training requirement should be a prime consideration when new equipment is deployed for the first time.

d. Trisponders worked very well for the boat survey. The only problems encountered were a breakdown of the weather seal on two units and the limited seven to ten mile range of the equipment. This range necessitated more geodetic control points. It was the only system used by the boats the last two SURVOPS in Panama and was extremely dependable. It is recommended that the Autotape be replaced with trisponders because of their greater flexibility.

e. Lack of Test/Calibration Equipment and repair of test equipment were also major problems. Some test equipment capable of checking power, frequency or receiver sensitivity of the trisponders should be supplied. Remote operational areas and long term operations plus required maintenance on equipment not on the OCUNIT's SECAS, make the SPETERL an inadequate test equipment allowance. Extra test equipment should be provided. A recommended list is being compiled by this command and will be forwarded upon completion.

f. High Traffic areas make the HDAS System mandatory for reasonable survey results. The PDP-9 should have a high priority for repair parts support and repairs should not be delayed 2-3 months simply to wait for the ship to enter a yard period. The PDP-9 does require an excessive amount of time for repairs. The equipment is old and replacement of one board usually sets up a chain reaction effect necessitating the replacement of several others before the system is operational again. The software for the WANG computer should be improved to lessen the effects of an inoperable PDP-9 between now and the arrival of a replacement computer reported to be in the next two or three years.

g. The URC-35 HF Radio was a great maintenance headache and at one time the unit had no long range high frequency communications capability. A MOTU technical representative was called in for assistance and even he could get only two of the four radios operational. This problem was solved only by the acquisition of two WRC-1's.

There still exists a requirement for better parts support of the on board electronic, geodetic and boat equipment. An up-to-date SECAS and APL's would greatly simplify and improve operations in the remote areas that OCUNITS FOUR and FIVE must work in. Prompt procurement and shipment of parts or new equipment plus technical assistance and training in all areas of electronics maintenance would greatly aid shipboard personnel and increase survey efficiency.

3. Boats:

The availability of spare parts was the main problem concerning the boats. Parts were hard to come by in Panama and there was a pronounced delay for ordered parts to arrive from CONUS. The carrying of vital spare parts such as screws and shafts is strongly advised. Small parts for chain saws, outboard motors, etc., were available but very expensive when purchased from Panamanian stores. All spare parts should be procured prior to coming to Panama.

The Panama Canal Company can take care of major repairs such as boats, generators or engines. They did good work on generators and fair work on other repairs. MSC Balboa is the liaison office when dealing with Panama Canal Company. Periodic checks must be made with MSC for progress reports. Mr. Perry or Mr. Amnson are the people to talk with at MSC Balboa.

The qualification of coxswains and boat officers for Panama Canal boat licenses is mandatory for operations in Canal Zone waters. There must be at least one licensed person on each boat when in Canal Zone waters. Motorboat regulations for Canal Zone waters can be obtained from the Marine Bureau of the Panama Canal Company. The designated personnel should take the test as soon as possible since a failed test may not be retaken for a week.

Finally, a document should be carried on all boats, at the NAVAID sites and in the helicopter, explaining the operation in both Spanish and English. It should also show what authority has given permission for the operation in a particular area. HARSAP arranged for such a letter from the Guardia Nacional.

4. Vehicle Support:

The availability of spare parts is the biggest problem with vehicles. Although the transportation office for Naval Station Panama Canal is very helpful, inform them what type of vehicles to expect so they can stock up on parts. Mr. Jack Kerr is the person to contact for vehicles and he was extremely helpful.

Fuel is easily obtained from the Fuels Officer at Naval Station Panama Canal (Rodman). He has tank farms on both the North and South coasts that deliver or are accessible by vehicle.

5. Geodesy:

Geodetic control is readily available near the canal on the north coast; however, most stations are on Panama Canal datum with no order given, as previously documented in SURVOP 11-78. The Marine CST currently in Panama will be another good source of information on the control in this area. After the ship's arrival, it is recommended that the embarked marine survey team attempt to work independently from the ship, establishing sites as far in advance as possible to alleviate delays in the actual survey operation.

It would be advantageous to send an advance geodetic team to the north coast areas, outside the Canal Zone, to set up geoceiver stations prior to OCUNIT FIVE's arrival. Since control, for the most part, is nonexistent and will have to be established prior to surveying, recommend utilizing HARSAP and IAGS or IGN resources to conduct this advance geodesy. Most prospective NAVAID sites on the north coast cannot be reached by road and either boat or helo will have to be used.

Care must be taken in all instances to insure that local officials know that an operation is going on in their area and why before anything is done. Having someone that speaks Spanish and a representative of the Panamanian IGN is essential for most operations. HARSAP can make the necessary arrangements with the Panamanian officials.

6. Helicopter Operations:

For operations in Panama, the Army is the basic source of support. Developing the Army-Navy relationship over the Air Force can be advantageous due to the Army's less rigid operating structure, aircraft availability for reserve operations, and assistance in the maintenance areas. The Air Force must be utilized in certain situations which will require an interservice working agreement. The administrative office at Naval Station Panama Canal is familiar with the needed paperwork.

When utilizing aircraft to offload or backload sites, diplomatic clearance for the area must be obtained for each aircraft involved. The HARSAP office is very helpful in setting this up.

The Army Tropical Test Center at Fort Clayton can provide excellent assistance with metal analysis which could expedite returning the aircraft to UP status. This is the only facility available in Panama for this service.

The Army did fly a few missions to support the survey work. Having the Army available as a backup for getting men and equipment to and from remote sites on short notice was extremely helpful on those occasions when the ship's helo was down.

7. Weather:

The Panama area is under the influence of a typical monsoon type climate with rain expected daily from April through October. Rains are normally one hour in duration, commencing around 1300 at the start of the season and progressively getting earlier in the day. During the mid-summer months twice a day rains can be expected, in the morning and again in the afternoon.

During the dry season, November through March, high winds become a significant problem; especially on the north coast due to the associated high sea state. Boat operations will be considerably hampered by this problem as a result.

The temperature remains in the 80's throughout the year and the relative humidity is normally high. Water temperature is also in the 80's.

OPERATIONAL STATISTICS

SURVOP 10-78: 31 JULY 1978   2 SEPTEMBER 1978
SURVOP 11-78: 3 SEPTEMBER 1978   7 OCTOBER 1978

	5-77 SURVOP	6-77 SURVOP	7-77 SURVOP	8-77 SURVOP	9-77 SURVOP	10-77 SURVOP	11-77 SURVOP
MILES STEAMED BY SHIP	9807	4748	4957	3187	4276	4748	2308
MILES OF OCEAN TRACK	4685	0	0	0	0	0	0
MILES OF SHIP HYDROGRAPHY	2643	2755	3240	1909	2309	1837	537
MILES OF LAUNCH HYDROGRAPHY	87	359.5	13.5	133	77	172	660

	1-78 SURVOP	2-78 SURVOP	3-78 SURVOP	4-78 SURVOP	5-78 SURVOP	6-78 SURVOP	7-78 SURVOP
MILES STEAMED BY SHIP	2627	3385	4061	2663	3897	1446	3039
MILES OF OCEAN TRACK	960	0	0	0	0	0	0
MILES OF SHIP HYDROGRAPHY	0	1143	1307	736	3197*	2038*	2679*
MILES OF LAUNCH HYDROGRAPHY	0	0	484	1062	0	594	126

	8-78 SURVOP	9-78 SURVOP	10-78 SURVOP	11-78 SURVOP	CUMULATIVE TOTAL
MILES STEAMED BY SHIP	3722	2844	0	932	62,647
MILES OF OCEAN TRACK	0	0	0	0	5,645
MILES OF SHIP HYDROGRAPHY	866	481	0	450	28,127*
MILES OF LAUNCH HYDROGRAPHY	1228	1461	1354	1730	9,541

* Includes USNS DE STEIGUER's 1340, 2013, and 2160 miles for SURVOPS 5, 6 and 7

Ship Statistics (USNS CHAUVENET)

	SURVOP 10-78		Cumulative Total	
	Days/Mi	%	Days/Mi	%
Calendar days in reporting period	34	100	511	100
Days inport	8	23.5	138	26
Days transit to/from survey area	0	0	41.5	8
Days available for ship survey	26		336.5	
Ship days lost	26	79.4	220.7	43
Installing/Removing NAVAID Sites	0		22.4	
NAVAID Resupply	0		11.1	
Calibration	0		12.8	
Equipment Failure	0		10.2	
Internal transit	0		13.3	
Weather	0		.8	
Objects in Survey Area	0		2.0	
Tide gauge installation	0		3.7	
Launch/Recover HSL's	0		15.1	
Ship Maintenance	26		26	
Days actual ship survey	0		115.7	23
Total ship survey miles	0		22,154	
Average per survey day	0		191.5	
Average per day deployment	0		43.4	

Boat Statistics

	SURVOP 10-78		Cumulative Total	
	Days/Mi	%	Days/Mi	%
Total available soundboat days	104	100	1,014	100
Soundboat days lost	84.7	81.4	871.6	86.6
Weather	1.0		18.7	
Transit	23.9		81.3	
Calibration	4.7		30.9	
Equipment Failure	1.6		140.1	
Equipment Limitation	5.0		84.4	
HSL Aground	.5		2.1	
HSL Inoperative	16		104.2	
HSL Survey not desired	32		293	
Soundboat actual survey days	19.3	18.6	146.3	14.4
Average number of boats operating per survey day	2.75		1.95	
Total soundboat survey miles	1,354		7,811	
Average per survey day	70		53.4	
Average per day available	13		7.7	

Ship Statistics (USNS CHAUVENET)

	SURVOP 11-78		Cumulative Total	
	Days/Mi	%	Days/Mi	%
Calendar days in reporting period	35	100	546	100
Days inport	6	17.1	139	25.6
Days transit to/from survey area	2	5.7	43.5	8.0
Days available for ship survey	27		363.5	
Ship days lost	24.3	69.4	244.1	44.7
Installing/Removing NAVAID Sites	0		22.4	
NAVAID Resupply	0		11.1	
Calibration	.5		13.3	
Equipment Failure	.3		10.5	
Internal transit	1.0		14.3	
Weather	.5		1.3	
Obstacles in Survey Area	.5		2.5	
Moored/Anchored for Repair	21		45	
Launch/Recover HSL's	.5		15.6	
Tide gauge installation	0		3.7	
Days actual ship survey	2.7	7.8	118.4	21.7
Total ship survey miles	450		22,604	
Average per survey day	166.7		190.9	
Average per day deployment	12.9		41.4	

Boat Statistics

	SURVOP 11-78 Days/Mi	%	Cumulative Total Days/Mi	%
Total available soundboat days	95	100	1109	100
Soundboat days lost	67.5	71.1	939.1	84.2
Weather	3		21.7	
Transit	15		96.3	
Calibration	2		32.9	
Equipment Failure	.5		140.6	
Equipment Limitation	3		87.4	
HSL Aground	0		2.1	
HSL Inoperative	15		119.2	
Installing/Removing NAVAID Sites	8		59.4	
Set Up Boat Camp	3		5.5	
Resupply NAVAID Sites	0		3	
HSL Survey not desired	18		311	
Soundboat actual survey days	27.5	28.9	175.2	15.8
Average number of boats operating per survey day	2.7		2.0	
Total soundboat survey miles	1,730		9,541	
Average per survey day	62.9		54.5	
Average per day available	18.2		8.6	

APPENDIX B: REVISED BASELINE, HYDROGRAPHIC SURVEY MODEL (2-HSL Case)

1. This is a model of a possible operation plan which uses times and distances for HSL and ship operations found in the memos dated 21 August 1979 and 4 September 1979 to construct a survey operation. This case *will be considered the "baseline" model because* the scenario used to construct it most closely resembles a typical hydrographic mapping operation.

2. It is assumed that only two HSL's are used in an operation.

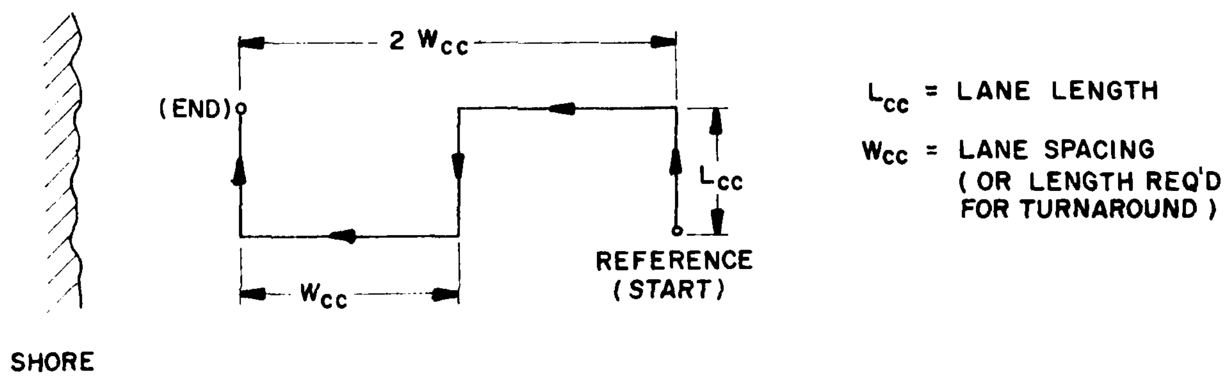
3. The operation covers a 24-hour period.

4. The HSL's survey only shallow waters.

a. HSL transit speed is 9 knots.
b. HSL survey speed is 8 knots.
c. HSL's operate from 0900-1600 (7 hours).
d. Cross-check lanes (parallel to the shore) are surveyed first; then the regular survey (perpendicular to the shore) is run.
e. Average survey mileage is limited by operating time (for 7 hours at 8 knots, an HSL can travel about 64.5 miles).
f. Survey lane width is 500 m (w_s = 0.316 mi). Scale is 1:50,000.
g. Cross-check survey lane width is assumed to be 10 times the survey lane widths, or 5,000 m (w_{cc} = 3.16 mi).

5. The following survey pattern was selected for one HSL. The HSL drop-off point is selected as the reference point.

a. The following cross-check survey pattern was chosen: two cross-check lanes were assumed.



b. The following mathematical relationships hold:

$$L_s = 2\ w_{cc} = 2(3.16\ \text{mi}) = 6.32\ \text{miles}$$

$$L_{cc} = n\ w_s$$

where n is to be determined.

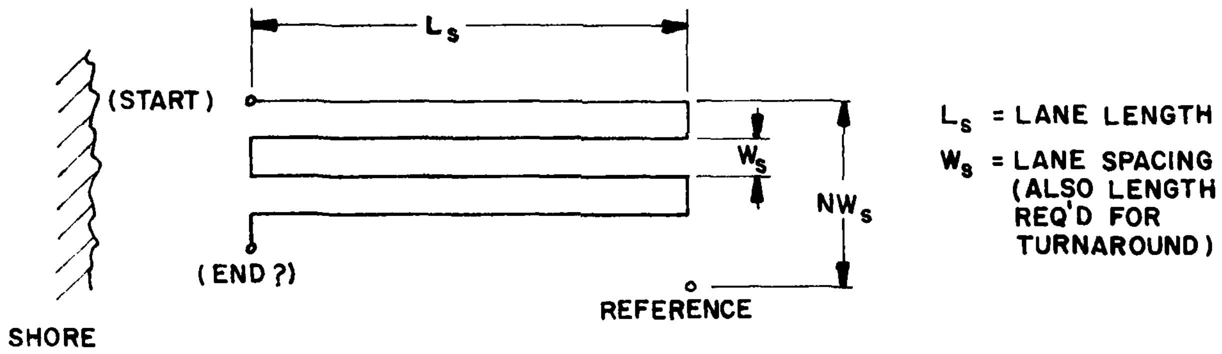
c. Total cross-check survey mileage is:

$$D_{cc} = 2(w_{cc}) + 3(n\ w_s)$$

$$= 2(3.16) + 3n(0.316)$$

$$= 6.32 + 0.948n$$

d. The following survey pattern was also selected for the HSL. This is to be performed after the cross-check survey.



e. Total survey mileage is:

$$D_s \cong n(L_s + w_s)$$

$$= n(6.32 + 0.316)$$

$$= 6.636n$$

f. Therefore,

$$\text{Total Distance Surveyed} \cong D_{cc} + D_s$$

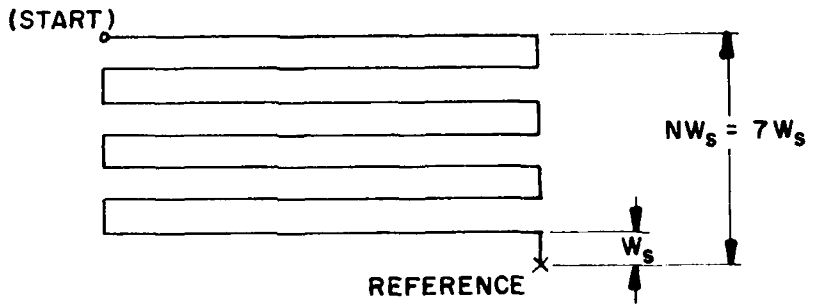
$$64.5 \text{ mi} = (6.32 + 0.948n) + 6.636n$$

$$58.18 = 7.584n$$

$$n = \frac{58.18}{7.584} = 7.67$$

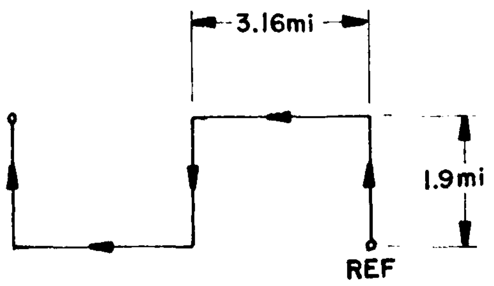
Hence, use n = 7 for estimating the most reasonable pattern.

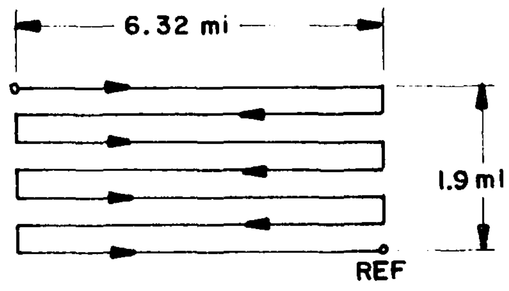
g. Using n = 7 (lane + turnaround) lengths causes the survey pattern to end at an awkward location as shown in the following sketch. Note that the last lane will NOT be surveyed by the HSL.



If the last "turnaround length" (w_s) before reaching the reference is eliminated, the survey will end exactly at the reference point.

h. Adjusting the cross-check and normal survey patterns to reflect this change gives the following patterns.





i. Total Mileage Surveyed $= D_{cc} + D_s$

$= [2(3.16) + 3(1.9)] + [7(6.32) + 6(0.316)]$

$= 12.02 + 46.136$

$= 58.16$ miles

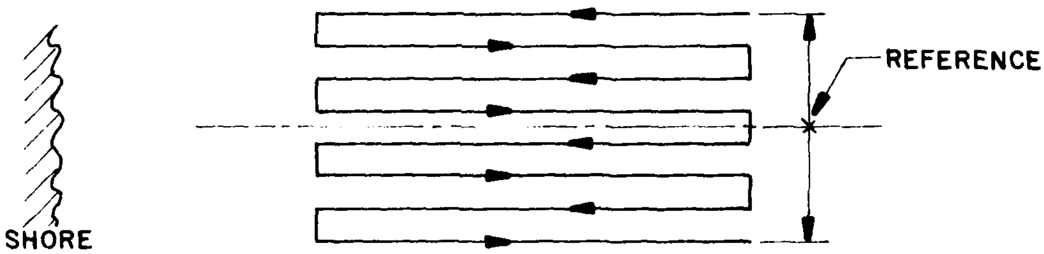
j. Time required to survey this distance is:

$$t_H = \frac{58.16 \text{ miles}}{8 \text{ knots } (1.151 \text{ mph/knots})} = 6.32 \text{ hours}$$

k. Total area surveyed = (1.9×6.32) mi^2 = 12.0 mi^2 (one HSL)

l. Hence, the above patterns appear to be reasonable, considering that the additional time (about 40 minutes) may be consumed by unplanned delays, etc.

6. Two HSL's are assumed to be used in this model. The most efficient mode of operation for them is when they run survey patterns which are the mirror image of each other when viewed from a plane perpendicular to the shore, and running through the reference point. The following sketch illustrates this:



Hence, the total area surveyed by the two HSL's is:

$$A_H = 2 \times 12.0 \text{ mi}^2 = 24.0 \text{ mi}^2$$

7. During the time that the HSL's are surveying the shallow waters, the ship can survey the area between the shallow (near-shore area) and the deep waters (out to 100 miles). This area will be referred to as "intermediate" waters.

a. Ship transit speed is 12 knots.
b. Ship survey speed is 10 knots.
c. Operation is assumed between 0900 and 1600 (7 hours).
d. Cross-check lanes and survey lanes are defined in a manner similar to the HSL lanes, except that a 1:100,000 scale was used. Cross-check lane widths of 10,000 m and survey lane widths of 1,000 m were assumed.

e. Survey range is limited by either the operation time limit (7 hours) or the restriction that the ship be no more than 4 hours away from the (farthest) HSL, whichever is less. That is, the ship has only 7 hours to perform the survey before it picks up the HSL's. This means it can only survey a distance at survey speed (10 knots):

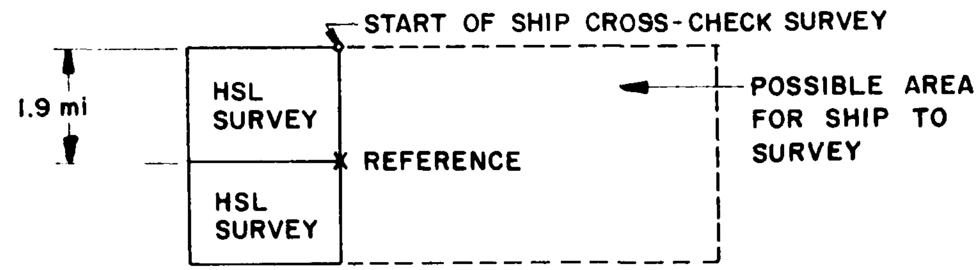
$$D_1 = (10\text{ knots})\,(1.151\text{ mph/knot})\,(7\text{ hours}) = 81\text{ miles}$$

before it must reach the reference point at the end of the 7-hour operation. Comparing this distance with the 4-hour separation restriction (transit speed is 12 knots):

$$D_2 = (12\text{ knots})\,(1.151\text{ mph/knot})\,(4\text{ hours}) = 55.3\text{ miles, max}$$

As concluded in the original (August 1979) model description, a comparison between these two criteria shows the former (81 miles) to be the more stringent requirement, and therefore the restriction which applies.

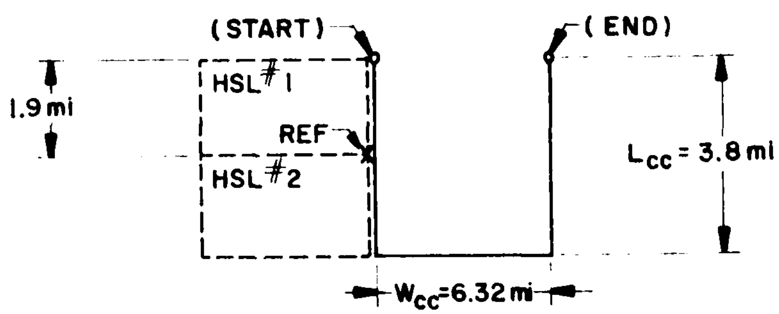
f. First, it is assumed that the mother ship transits from the reference point to the edge of the HSL survey area (see sketch).



This is where the ship cross-check survey will begin. Transit time to this point is approximately (at 12 knots):

$$t_T = \frac{1.9\text{ miles}}{12\text{ knots}\,(1.151\text{ mph/knot})} = 0.138\text{ hr} = 8\text{ minutes}$$

g. The following cross-check survey pattern was selected.



Total cross-check survey mileage at 10 knots is:

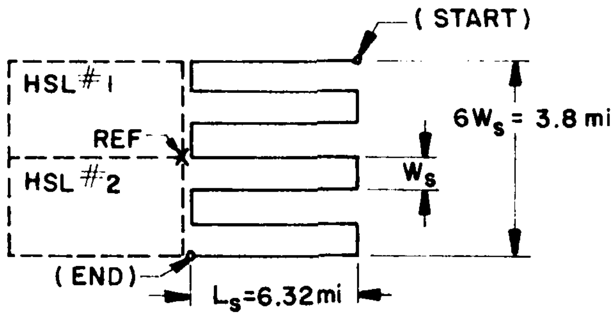
$$D_{cc} = 2L_{cc} + W_{cc}$$

$$= 2\,(3.8) + (6.32) = 13.9 \text{ miles}$$

Time to survey this mileage is:

$$t_{cc} = \frac{13.9 \text{ miles}}{10 \text{ knots } (1.151 \text{ mph/knot})} = 1.21 \text{ hours}$$

h. The following pattern was chosen for the normal survey.



This pattern will cover as much distance (parallel to the shore) as the two HSL's. Total survey mileage is:

$$D_s = 7\,(6.32) + 6\,(0.632) \text{ miles} = 48.03 \text{ miles}$$

The time to survey this mileage is:

$$t_s = \frac{48.03 \text{ miles}}{10 \text{ knots } (1.151 \text{ mph/knot})} = 4.17 \text{ hours}$$

i. Transiting back to the reference (1.9 miles at 12 knots) will again take only about 8 minutes, as before.

j. Hence, time expended so far by the ship is:

$$t = t_{cc} + t_s + 2t_I$$

$$= 1.21 + 4.17 + 2(0.138)$$

$$= 5.66 \text{ hours} < 7 \text{ hours},$$

leaving about 1.34 hours that the ship can use for surveying. This extra time translates to a distance of:

$$\text{Dist} = (10 \text{ knots})(1.151 \text{ mph/knot})(1.34 \text{ hours}) = 15.42 \text{ miles}$$

Adding another survey lane to the existing pattern and adjusting the cross-check lanes accordingly increases the survey mileage by the amounts:

$$\Delta D_{cc} = 2\,(0.632 \text{ mi}) = 1.264 \text{ miles}$$

$$\Delta D_s = (6.32 + 0.632) \text{ mi} = 6.952 \text{ miles}$$

Total change in mileage for one additional lane is:

$$\Delta D = \Delta D_{cc} + \Delta D_s = 8.216 \text{ miles.}$$

Hence, only one more lane can be added. The total mileage surveyed is therefore:

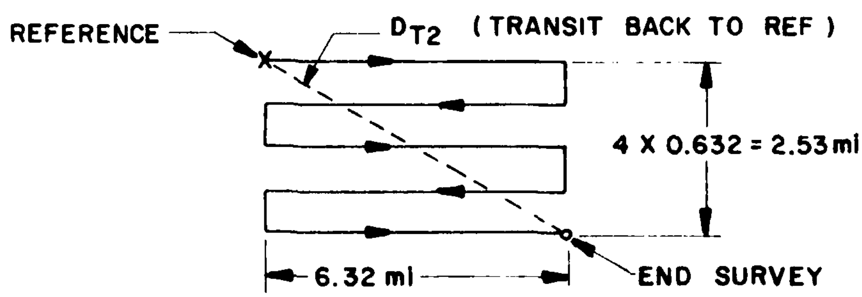
$$D_{tot} = D_s + D_{cc} + \Delta D = 48.03 + 13.9 + 8.216 \text{ miles}$$

$$= 70.15 \text{ miles}$$

Time to survey this mileage is:

$$t_{tot} = \frac{70.15 \text{ miles}}{10 \text{ knots}\,(1.151 \text{ mph/knot})} = 6.1 \text{ hours}$$

k. Computing the time required for the ship to transit back to the reference point to pick up the HSL's:



$$D_{T2} = \sqrt{(2.53)^2 + (6.32)^2} = 6.81 \text{ miles}$$

$$t_{T2} = \frac{6.81 \text{ miles}}{12 \text{ knots}\,(1.151 \text{ mph/knot})} = 0.49 \sim 0.5 \text{ hours}$$

l. Total time consumed (survey + transit time) is:

$$t_T = 6.1 + 0.138 + 0.5 \text{ hours} \approx 6.7 \text{ hours},$$

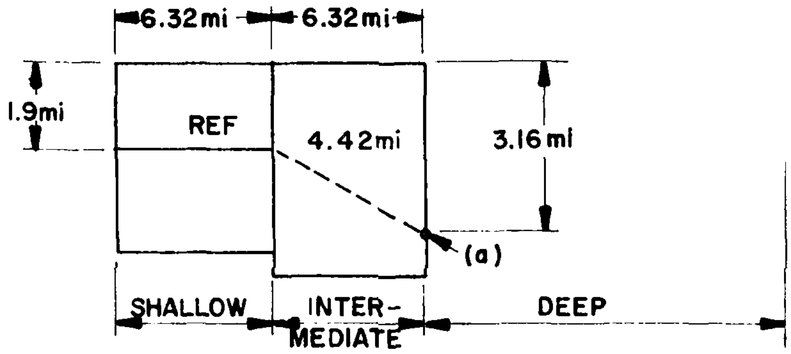
which compares favorably with the 6.32 hours it takes for the HSL's to simultaneously survey the shallow water.

m. Consequently, the total area surveyed is:

$$A_i = 6.32 \text{ mi} \times 7\,(0.632 \text{ mi}) = 27.96 \cong 28 \text{ mi}^2$$

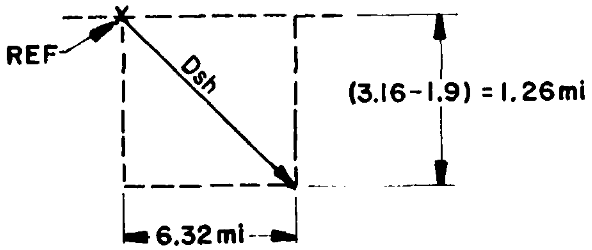
Note that the ship can survey more area than the two HSL's, and will eventually get ahead of the HSL's.

8. The survey pattern so far is as follows:



9. After the ship picks up the HSL's, it can traverse to point (a) [see above sketch].

a. The distance is:



$$D_{sh} = \sqrt{(6.32)^2 + (1.26)^2} = 6.45 \text{ miles}$$

Time to traverse this distance is:

$$t_{sh} = \frac{6.45 \text{ miles}}{12 \text{ knots } (1.151 \text{ mph/knot})} = 0.47 \text{ hours} \simeq 0.5 \text{ hours}$$

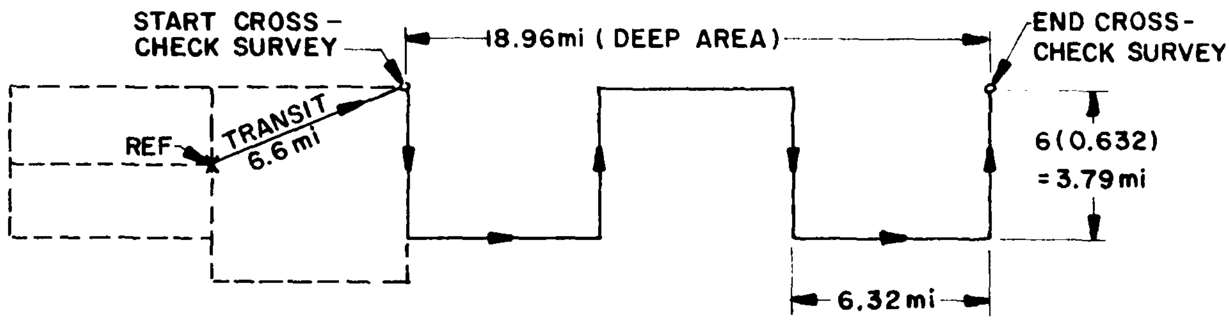
b. In the deep area (beyond the intermediate area), the cross-check and survey lane widths are assumed to be (on a scale of 1:250,000):

$$w_{cc} = 6.32 \text{ miles} = 10{,}000 \text{ m}$$

$$w_s = 0.632 \text{ miles} = 1{,}000 \text{ m}$$

c. The time to complete the deep area survey is assumed to be 14 hours. Considering that it takes about 0.5 hours to traverse to the start of survey position, 13.5 hours are left for surveying and traversing to a new reference point (i.e., start of survey for the next day).

d. The following cross-check pattern was assumed for the ship.



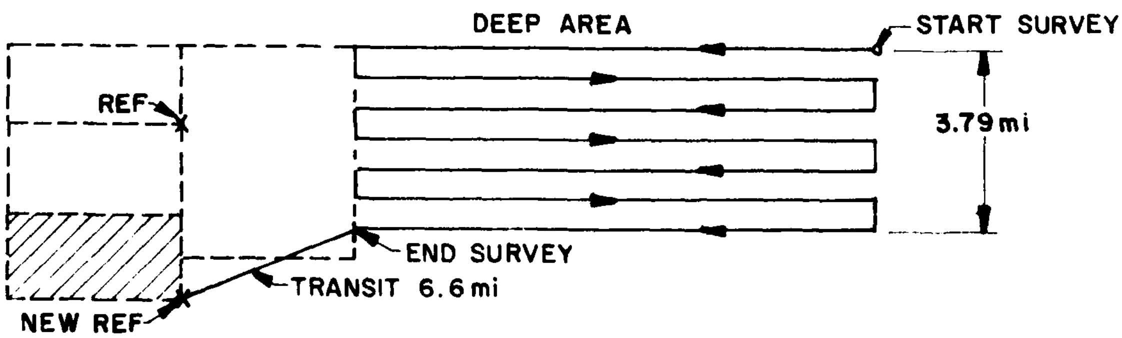
The mileage surveyed by the ship is:

$$D_{cc} = 4(3.79) + 3(6.32) = 34.12 \text{ miles}$$

Time to survey this mileage is:

$$t_{cc} = \frac{34.12 \text{ miles}}{10 \text{ knots } (1.151 \text{ mph/knot})} = 2.96 \text{ hours}$$

e. Also, the following survey pattern was assumed:



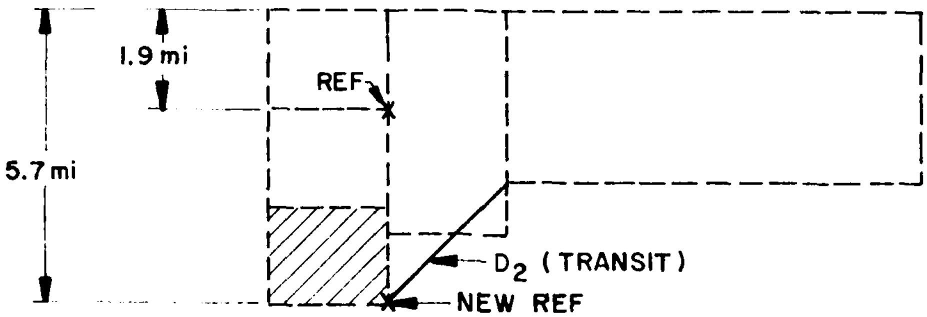
The mileage survey for this pattern is:

$$D_s = 7 \times 18.96 + 6(0.632) = 136.51 \text{ miles}$$

Time to complete this action is:

$$t_s = \frac{136.51 \text{ miles}}{10 \text{ knots } (1.151 \text{ mph/knot})} = 11.86 \text{ hours}$$

f. At the end of the normal survey, it is expected that the ship return to the new reference to start the new day's operations. Estimated distance to transit to the new reference point (where the survey will start the next day) is from the geometry:



$$D_2 = \sqrt{[3(1.9) - 3.8]^2 + (6.32)^2} = 6.6 \text{ miles}$$

Transit time is:

$$t_2 = \frac{6.6 \text{ miles}}{12 \text{ knots } (1.151 \text{ mph/knot})} = 0.48 \text{ hours}$$

g. Total time consumed by the ship (in deep waters):

$$t_{Tot} = t_{sh} + t_{cc} + t_s + t_2$$

$$= 0.47 + 2.96 + 11.86 + 0.48 = 15.77 \text{ hours,}$$

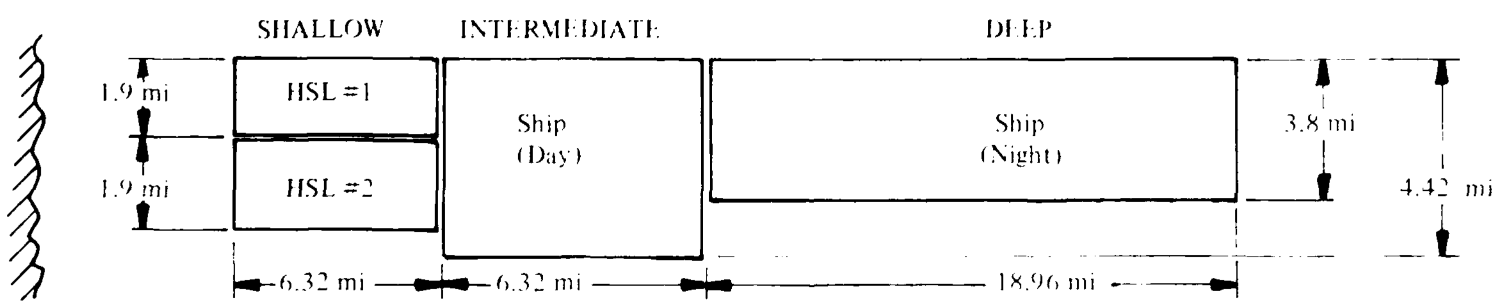
which is reasonable.

h. Total area surveyed by the ship in deep waters is:

$$A_d = (18.96 \times 3.79) \text{ mi}^2 = 71.86 \text{ mi}^2$$

BASELINE MODEL: TWO HSL'S

Survey Area	Lane Spacing		Survey Mileage	Area (sq. mi.)
	Cross-check Survey	Normal Survey		
1. Shallow (Two HSL's)	3.16 mi (5,000 mi)	0.316 mi (500 m)	116.3 mi	24.02 mi^2
2. Intermediate (Ship Day)	6.32 mi (10,000 m)	0.632 mi (1,000 m)	70.15 mi	27.93 mi^2
3. Deep (Ship Night)	6.32 mi (10,000 m)	0.632 mi (1,000 m)	170.63 mi	72.05 mi^2



APPENDIX C: TWO-HSL CASE; 10-HOUR OPERATION, 24-HOUR ENDURANCE

1. The assumptions made for this case are:

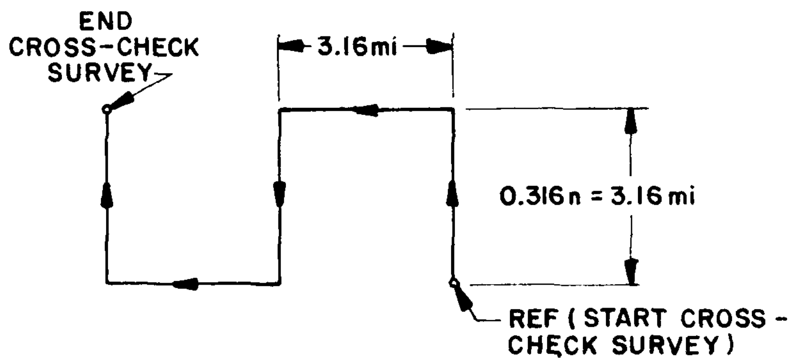
   a. Two HSL's are used.
   b. Both operate for 10 hours per day.
   c. HSL's are not recovered after 10 hours.
   d. Ship operates for 24 hours.
   e. Ship and HSL's rendezvous after 24 hours.
   f. Lane widths assumed are:

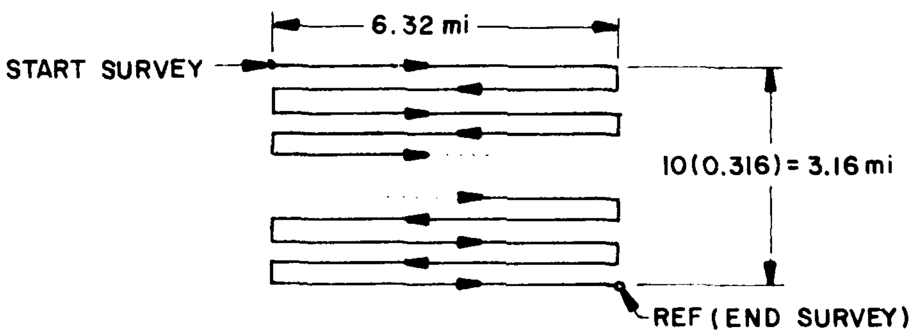
	Cross-check	Normal Survey
Shallow Area	5,000 m	500 m
Deep Area	10,000 m	1,000 m

   g. HSL survey speed is 8 knots, and transit speed is 9 knots.
   h. Ship survey speed is 10 knots, and transit speed is 12 knots.

2. The number of HSL cross-check lanes are assumed to be the same as in the "Two-HSL Baseline" Case. This permits easier comparison between the two cases.

   a. The following patterns were assumed for the shallow area (HSL) survey.

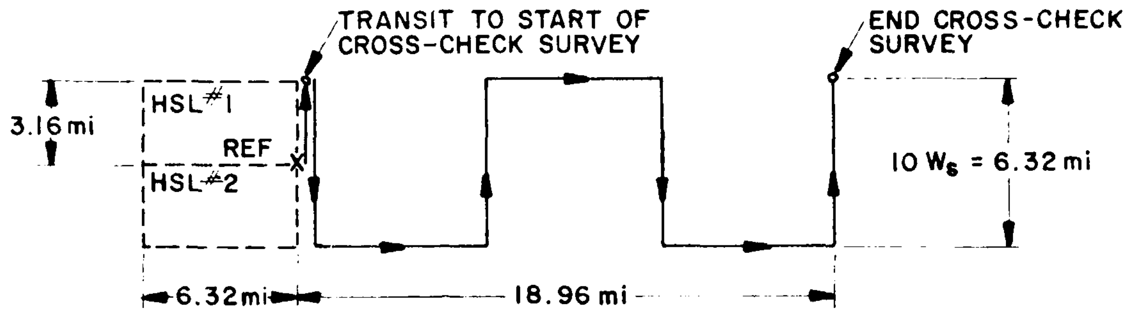




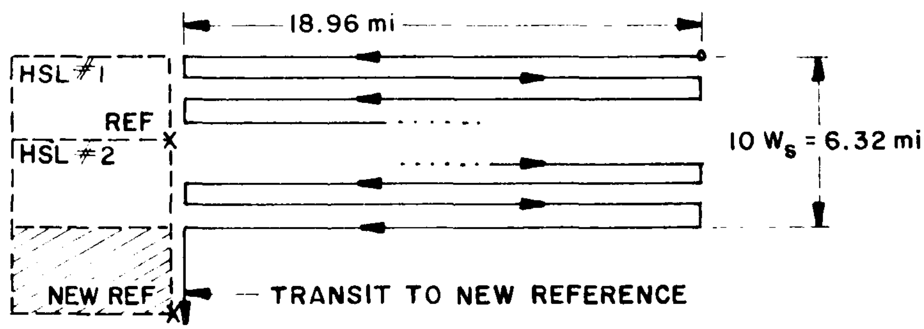
b. Total mileage (survey) = 88.48 miles.
c. Area surveyed (per HSL) = 40.0 sq mi.

3. Ship operations were assumed to follow the patterns given below:

a. Cross-check survey:



b. Normal survey:

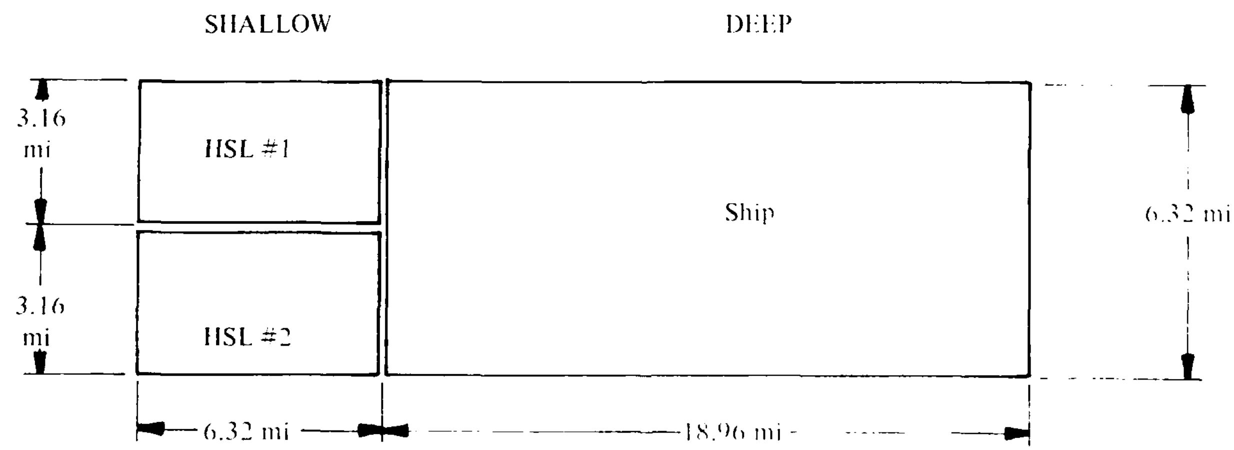


c. Transit time to new reference = 14 minutes.
d. Total survey mileage = 259.12 miles.
e. Area surveyed = 120 sq. mi.

4. A summary of results is found on the next page.

Two HSL Case (10-hour operation, 24-hour endurance)

SURVEY AREA	Area Surveyed (sq mi)	Survey Mileage (mi)	Operating Time (hr)
1. Shallow Area (Two HSL's 10 hrs each)	40 mi^2 (total)	88.48 mi (each)	9.61 hrs (each)
2. Deep Area (Ship - 24 hrs)	120 mi^2	259.12 mi	23.0 hrs



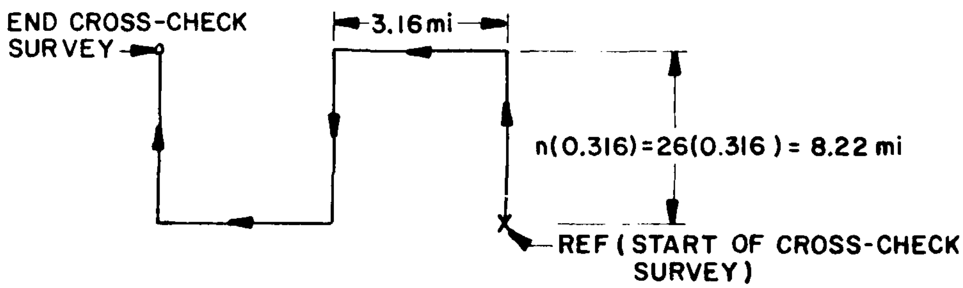
APPENDIX D: TWO-HSL CASE; 24-HOUR OPERATION

1. Assumptions made for this case are:

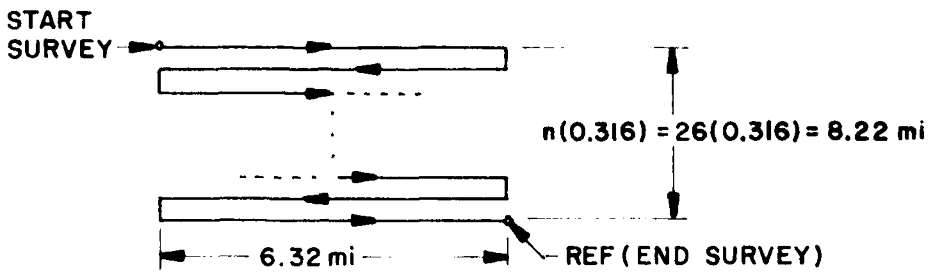
   a. Two HSL's used.
   b. Both operate for 24 hours.
   c. HSL's not recovered for 24 hours.
   d. Ship operates for 24 hours.
   e. Lane widths are the same as two HSL case (10-hour operation, 24-hour endurance).
   f. Speeds are the same as previous cases.

2. The following patterns were chosen: (shallow area survey)

   a. Cross-check survey pattern: (one HSL)



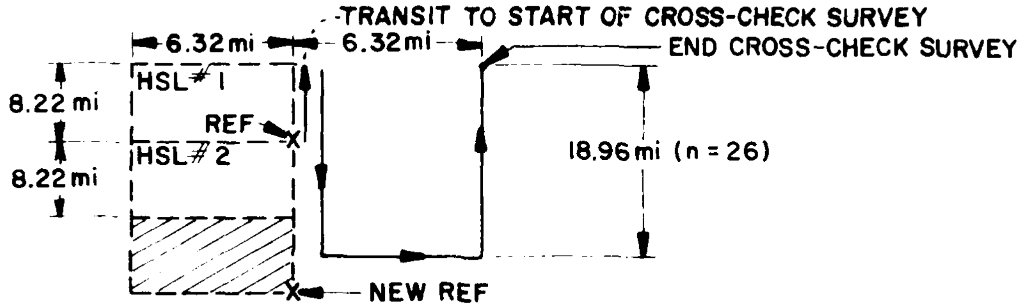
   b. Normal survey: (one HSL)



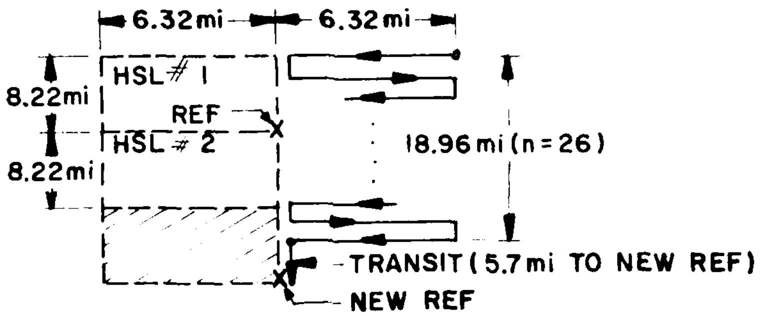
   c. Total survey mileage = 209.8 mi.
   d. Area surveyed (per HSL) = 104 mi^2.

3. Deep operation patterns were chosen as follows:

a. Cross-check survey: (ship)



b. Normal survey: (ship)



c. Total ship survey mileage = 259.12 mi.
d. Area surveyed = 120 sq mi.
e. A summary of results is found in table 1.

4. As an alternate pattern that can be used for deep area survey is the same as that used in the two HSL Case (10-hr operation, 24-hr endurance). A summary sheet is found in table 2. Note that the difference between the two cases is in ship operating time.

Table D-1. Two HSL case (24-hour operation)

SURVEY AREA	Area Surveyed (sq mi)	Survey Mileage (mi)	Operating Time (hr)
1. Shallow Area (2 HSL's 24 hrs each)	104 mi^2 (total)	209.8 mi (each)	24.38 hrs (each)
2. Deep Area (Ship 24 hrs)	120 mi^2	259.1 mi	23.51 hrs

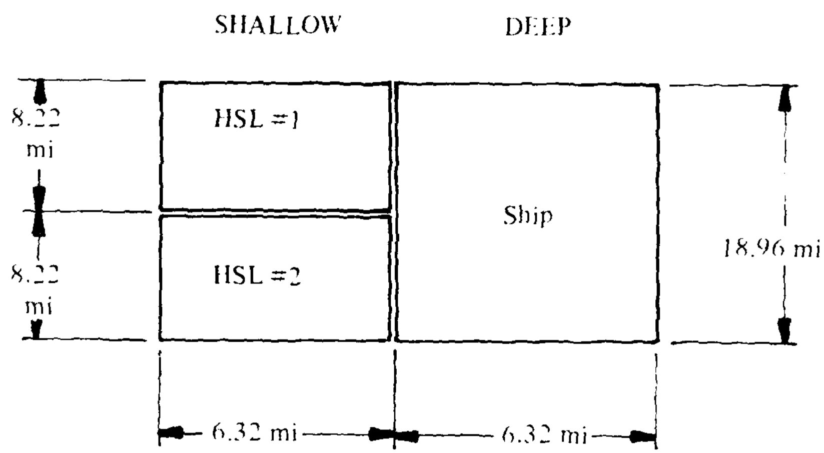
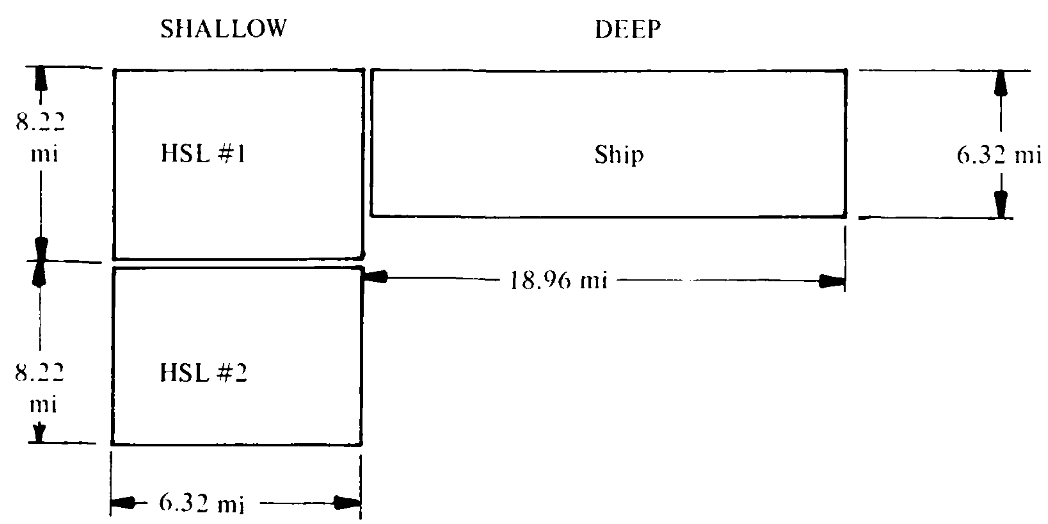


Table D-2. Two-HSL case (24-hour operation).

SURVEY AREA	Area Surveyed (sq mi)	Survey Mileage (mi)	Operating Time (hr)
1. Shallow Area (2 HSL's 24 hrs each)	104 mi^2 (total)	209.8 mi (each)	24.38 hrs (each)
2. Deep Area (Ship 24 hrs)	120 mi^2	259.1 mi	23.83 hrs



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